The Penny Cyclopædia of the Soci
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Society for the Diffusion of Useful Knowledge (Great Br

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VOLUME XVI.

MURILLO——ORGAN.

LONDON:

CHARLES KNIGHT AND Co., 22, LUDGA

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more conspicuous than that of a *Flycatcher.*

M. Lesson makes the Muscicapidæ consist of the genera *Tyrannus, Monacha, Eurylaimus, Platyrhynchus, Todus, Myiagra, Muscicapa, Alectrurus, Drymophila, Formicivora, Rhipidura, Seisura, Psophodes,* and *Enicurus.*

Mr. Swainson (*Classification of Birds*) is of opinion that the Water-chats (*Fluvicolinæ*) seem to connect the Tyrant Shrikes with the Flycatching family, or *Muscicapidæ,* the most insectivorous of the *Dentirostres;* a group, he remarks, hardly less numerous than that of the Warblers, and composed, like them, almost entirely of small birds. Both families, he continues, are insectivorous, that is, habitual devourers of insects; but very many of the warblers (even in the more typical genera) feed also upon fruits, of which the robin, the blackcap, and the whitethroat are notable examples. 'The Flycatchers however,' adds Mr. Swainson, 'properly so called, seem to be strictly and exclusively insectivorous, or, at least, it has not yet been ascertained that any of the species composing the typical group *Muscicapinæ* ever partake of fruits. This peculiarity of diet, independent of many others, separates them from the warblers on one side, and from the *Ampelidæ,* or Chatterers, on the other; while another is to be found in the mode or manner of their feeding. The warblers fly about, hunting down their prey, searching among trees, and roaming from place to place after their favourite food; hence they become ambulating flycatchers, and their feet are consequently large and strong in comparison to the size of their bodies. We need only look to the gold-crested and wood warblers as exemplifications of this remark, even among those species which frequent trees; but in such, as in the Stonechats, *Saxicolinæ,* and *Motacillinæ,* as habitually walk, the feet are much stronger and the shanks more lengthened. Now, the very reverse of this structure is the typical distinction of the Flycatchers; their legs are remarkably small and *weak,*—more so, perhaps, than those of any dentirostral birds,—showing at once that their feet are but little used; and such we find to be the case. The Flycatchers constitute the fissirostral type of form among the leading divisions of the *Dentirostres,* and they consequently exhibit all the chief indications of that primary type of nature, as it is exhibited in the feathered creation. These, as the intelligent ornithologist already knows, are manifested in a large and rather wide mouth and bill; short, feeble, and often imperfect feet; great powers of flight and often a considerable length of wing: the development of this latter structure is not always apparent, but it is the peculiar power of their flight upon which they chiefly depend for procuring subsistence. They are mostly sedentary, and only dart upon such insects as come within a sudden swoop, without attempting to pursue their game further, if unsuccessful in the first instance: they return, in fact, to the spot they left, or to another very near, and there await patiently until another insect passes within the proper distance. This habit of feeding at once explains the reason of the feet being so small and weak, by showing that they

Genera·—*Icteria,* V
Bonap.
In considering this
remember that it only
North America.
Mr. Swainson thus d
Stature small. Bil
length, broad: the edg
that of the lower; the
tus wide, defended wit
wards Feet almost
types, where of course
Feed solely upon inse
sedentary.

Sub

Bill strong, broad, m
with strong bristles.
typical *Ampelinæ.* La
Mr. Swainson is of o
type of this family, and
nean writers this rema
while by others, even
an *Ampelis;* and he th
be reconciled, by view
ment—as the connecti
remarks that all the
system, so far as we y
but there is unquestio
also upon fruits, thus
the two families whic
there is much of the f
but it is wide and mo
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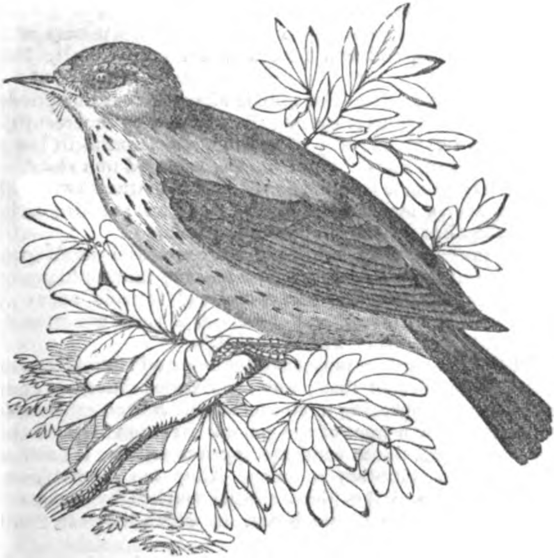
remarkably short for t
only, like those of the
characters, in the opi
out this genus as the f
of the families of *Musc*

Querula, Vieill. and
former as an example.
Generic Character.—
long and straight. N
flected feathers. Wing
Toes unequal; inner t
hind toe. Tail even.
Example, *Querula r*
Description.—Black
Muscicapa rubricollis
Locality and Habits
in the woods in pursui

their prey after the manner of the old birds.

The sexes are alike in plumage. The young, for a short time after they begin to fly, have the feathers tipped with yellowish-white, which gives them a mottled appearance. The chirp of this Flycatcher, its only note, is weak.



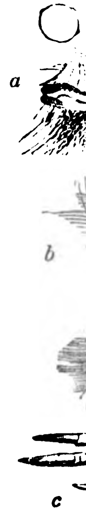
Muscicapa Grisola (male).

Eurylaiminæ.

Size large. Structure powerful. Bill short, excessively broad; the upper mandible convex above, dilated at its base, and the margins folding over those of the upper mandible; the tip abruptly hooked. Wings rather short. Feet strong, moderate. The outer toe connected for half its length to the middle toe; hinder toe long; inner toe shortest.

Mr. Swainson, who gives this as the character of the subfamily, observes that the *Eurylaiminæ* are the most remarkable birds of the whole family; the species are very few, and their geographical limits seem to be restricted to the hottest parts of India, where they inhabit the forests. 'In size,' continues Mr. Swainson, 'they exceed all others, save the genus *Querula*, in this family, being about the size of starlings, while the enormous breadth of their bills and the peculiar brightness of their colouring render it impossible for the student to mistake them for any other genus. The bill is not only excessively broad, but the margins of the base are so dilated that they often project over those of the lower mandible, while its substance seems much more solid than in the ordinary Flycatchers. Although very few species have hitherto been discovered, it is quite clear that

Generic Character.-
mandible very thin, pa
transverse, oval; the a
second almost imperce



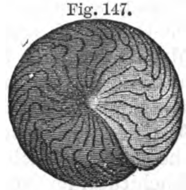
a, bill of Eurylaimus Jav
anterior toes of the same, to s

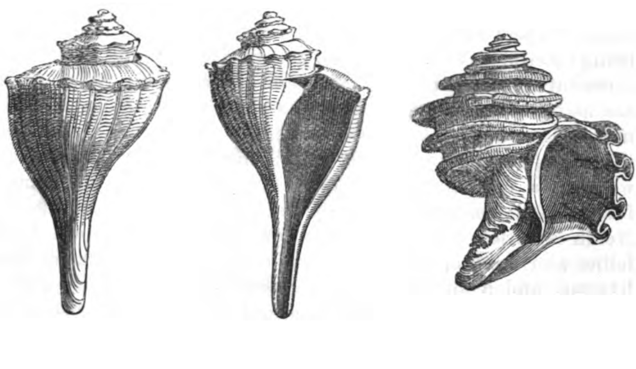
Example, *Eurylain*
fieldii, Temm.).

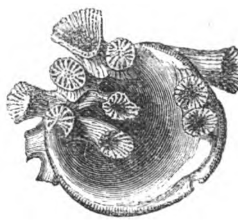
Description.—Entir
of the neck, and the wh
violet, or rather vinou
the forehead around t
the neck brown, darke
sooty. Wings very d
tense near the should
A yellow streak betwe
Wings beneath from
which borders the win
the base and yellow a
yellow, which is the c
tail-feathers black, fo
white transverse ban
external feathers the b
broader. Bill reddish
dibles irregularly var
tremity; culmen yell
and shining. Tarsi an
inclining to black.

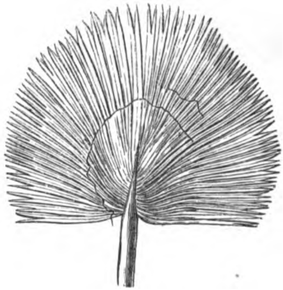
Geographical Distr
is of opinion that fro

Fig. 147.



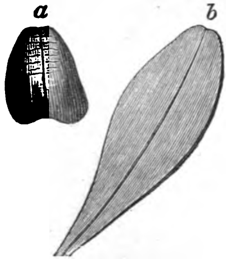






from the Lower Miocene strata of Lucerne. They may have fallen out of a decayed cone in the same way as often happens

Fig. 152.



a. Fruit of a fossil Banksia.
b. Leaf of Banksia Deekiana.

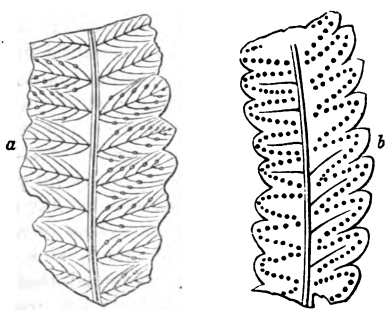
Fig. 153.

Sequoia Langsdorfii. Ad. Brong, ⅓ natural size. Rivaz, near Lausanne. (Heer, Pl. 21, fig. 4.) Upper and Lower Miocene and Lower Pliocene, Val d'Arno.

a. Branch with leaves. *b.* Young cone.

to the seeds of the spruce fir, *Pinus abies*, found scattered over the ground in our woods. It is a known fact that among the living Proteaceæ the cones are very firmly attached to the

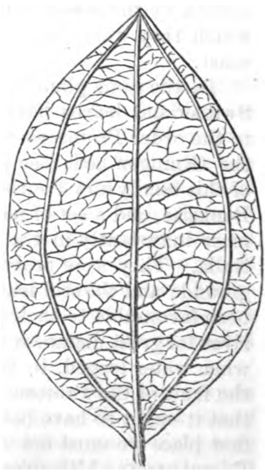
Fig. 154.



Lastræa stiriaca, Ung. (Heer's Flora, Pl. 143, fig. 8.)
Natural size. Lower and Upper Miocene, Switzerland.

a. Specimen from Monod, showing the position of the sori on the middle of the tertiary nerves.
b. More common appearance, where the sori remain and the nerves are obliterated.

Fig. 155.



Cinnamomum Rossmässleri, Heer. *Daphnogene cinnamomifolia*, Unger. Upper and Lower Miocene, Switzerland and Germany.

branches, so that the seeds drop out without the cone itself falling to the ground; and this may perhaps be the reason why,

in some instances in which fossil seeds have been found, no traces of the cone have been observed.

Among the Coniferæ the *Sequoia* (fig. 153) is common at Rivaz, and is one of the most universal plants in the Lowest Miocene of Switzerland, while it also characterises the Miocene Brown Coals of Germany and certain beds of the Val d'Arno, which I have called Older Pliocene, p. 190.

Among the ferns met with in profusion at Monod is the *Lastræa stiriaca*, Unger, which has a wide range in the Miocene period from strata of the age of Œningen to the lowest part of the Swiss molasse. In some specimens, as shown in figure 154, the fructification is distinctly seen.

Among the laurels several species of *Cinnamomum* are very conspicuous. Besides *C. polymorphum*, before figured, p. 201, another species also ranges from the Lower to the Upper Molasse of Switzerland, and is very characteristic of different deposits of Brown Coal in Germany. It has been called *Cinnamomum Rossmässleri* by Heer (see fig. 155). The leaves are easily recognised as having two side veins, which run up uninterruptedly to their point.

American character of the flora.—If we consider not merely the number of species but those plants which constitute the mass of the Lower Miocene vegetation, we find the European part of the fossil flora very much less prominent than in the Œningen beds, while the foreground is occupied by American forms, by evergreen oaks, maples, poplars, planes, Liquidambar, Robinia, Sequoia, Taxodium, and ternate-leaved pines. There is also a much greater fusion of the characters now belonging to distinct botanical provinces than in the Upper Miocene flora, and we shall find this fusion still more strikingly exemplified as we go back to the antecedent Eocene and Cretaceous periods.

Professor Heer has advocated the doctrine, first advanced by Unger to explain the large number of American genera in the Miocene flora of Europe, that the present basin of the Atlantic was occupied by land over which the Miocene flora could pass freely. But other able botanists have shown that it is far more probable that the American plants came from the east and not from the west, and, instead of reaching Europe by the shortest route over an imaginary Atlantis, migrated in an opposite direction, crossing the whole of Asia.

Arctic Miocene Flora.—But when we indulge in speculations as to the geographical origin of the Miocene plants of Central Europe, we must take into account the discoveries recently made of a rich terrestrial flora having flourished in the Arctic regions in the Miocene period from which many species

may have migrated from a common centre so as to reach the present continents of Europe, Asia, and America. Professor Heer has examined the various collections of fossil plants that have been obtained in N. Greenland (lat. 70°),[3] Iceland, Spitzbergen, and other parts of the Arctic regions, and has determined that they are of Miocene age and indicate a temperate climate.[4] Including the collections recently brought from Greenland by Mr. Whymper, the Arctic Miocene flora now comprises 353 species, and that of Greenland 169 species, of which 69, or nearly two-fifths, are identical with plants found in the Miocene beds of Central Europe. Considerably more than half the number are trees, which is the more remarkable since at the present day trees do not exist in any part of Greenland even 10° farther south.

More than 50 species of Coniferæ have been found, including several Sequoias (allied to the gigantic Wellingtonia of California), with species of Thujopsis and Salisburia now peculiar to Japan. There are also beeches, oaks, planes, poplars, maples, walnuts, limes, and even a magnolia, two cones of which have recently been obtained, proving that this splendid tree not only lived but ripened its fruit within the Arctic circle. Many of the limes, planes, and oaks were large-leaved species, and both flowers and fruit, besides immense quantities of leaves, are in many cases preserved. Among the shrubs were many evergreens, as *Andromeda*, and two extinct genera, *Daphnogene* and *M'Clintockia*, with fine leathery leaves, together with hazel, blackthorn, holly, logwood, and hawthorn. *Potomogeton*, *Sparganium*, and *Menyanthes* grew in the swamps, while ivy and vines twined around the forest trees, and broad-leaved ferns grew beneath their shade. Even in Spitzbergen, as far north as lat. 78° 56′, no less than 179 species of fossil plants have been obtained, including *Taxodium* of two species, hazel, poplar, alder, beech, plane-tree, and lime.[5] Such a vigorous growth of trees within 12° of the pole, where now a dwarf willow and a few herbaceous plants form the only vegetation, and where the ground is covered with almost perpetual snow and ice, is truly remarkable.

The identity of so many of the fossils with Miocene species of Central Europe and Italy not only proves that the climate of

[3] During the last English Polar Expedition to N. Greenland, 1875, twenty-five species of plants of Miocene age were found by Captain Feilden in Grinnell-land, 81° 45′ N. lat., and described by Prof. Heer, Q. J. G. Soc., vol. xxxiv. p. 66.

[4] Heer, Flora Fossilis Arctica, and Fossil-Flora von Alaska, 1869.

[5] Heer, Miocene Flora and Fauna of Spitzbergen. Stockholm, 1875.

Greenland was much warmer than it is now, but also renders it probable that a much more uniform climate prevailed over the entire northern hemisphere. This is also indicated by the whole character of the Upper Miocene Flora of Central Europe, which does not necessitate a mean temperature very much greater than exists at present, if we suppose such absence of winter cold as is proper to insular climates. Professor Heer believes that the mean temperature of North Greenland must have been at least 30° higher than at present, while an addition of 10° to the mean temperature of Central Europe would probably be as much as was required. The chief locality where this wonderful flora is preserved is at Atanekerdluk in North Greenland (lat. 70°), on a hill at an elevation of about 1,200 feet above the sea. There is here a considerable succession of sedimentary strata pierced by volcanic rocks. Fossil plants occur in all the beds ; and the erect trunks as thick as a man's body which are sometimes found, together with the abundance of specimens of flowers and fruit in good preservation, sufficiently prove that the plants grew where they are now found. At Disco Island and other localities on the same part of the coast, good tertiary coal is abundant, interstratified with beds of sandstone in some of which fossil plants have also been found, similar to those at Atanekerdluk.

Lower Miocene, Belgium.—The Upper Miocene Bolderberg beds, mentioned at p. 206, rest on a Lower Miocene formation called the Rupelian of Dumont. This formation is best seen at the villages of Rupelmonde and Boom, ten miles south of Antwerp, on the banks of the Scheldt, and near the junction with it of a small stream called the Rupel. A stiff clay abounding in fossils is extensively worked at the above localities for making tiles. It attains a thickness of about 100 feet, and, though very different in age, much resembles in mineral cha-

Fig. 156.

Leda (*Nucula*) *Deshayesiana*, Nyst., nat. size.

racter the 'London Clay,' containing, like it, septaria or concretions of argillaceous limestone traversed by cracks in the interior, which are filled with calc-spar. The shells, referable to about forty species, have been described by MM. Nyst and De Koninck. Among them *Leda* (or *Nucula*) *Deshayesiana* (see

fig. 156) is by far the most abundant; a fossil unknown as yet in the English tertiary strata, but when young much resembling *Leda amygdaloides* of the London Clay proper (see fig. 212, p. 249). Among other characteristic shells are *Pecten Hœninghausii*, and a species of *Cassidaria*, and several of the genus *Pleurotoma*. Not a few of these testacea agree with English Eocene species, such as *Actæon simulatus*, Sow., *Cancellaria evulsa*, Brander, *Corbula pisum* (fig. 158), and *Nautilus* (*Aturia*) *ziczac*. They are accompanied by many teeth of sharks, as *Lamna contortidens*, Ag., *Oxyrhina xiphodon*, Ag., *Carcharodon angustidens* (see fig. 195, p. 244), Ag., and other fish, some of them common to the Middle Eocene strata.

Kleyn Spawen beds.—The succession of the Lower Miocene strata of Belgium can be best studied in the environs of Kleyn Spawen, a village situated about seven miles west of Maestricht, in the old province of Limburg, in Belgium. In that region, about 200 species of testacea, marine and freshwater, have been obtained, with many foraminifera and remains of fish. In none of the Belgian Lower Miocene strata could I find any nummulites; and M. d'Archiac had previously observed that these foraminifera characterise his 'Lower Tertiary Series,' as contrasted with the Middle, and they therefore serve as a good test of age between Eocene and Miocene, at least in Belgium and the North of France.[6] Between the Bolderberg beds and the Rupelian clay there is a great gap in Belguim, which seems, according to M. Beyrich, to be filled up in the North of Germany by what he calls the Sternberg beds, and which, had Dumont found them in Belgium, he might probably have termed Upper Rupelian.

Lower Miocene of Germany.—*Rupelian Clay of Hermsdorf, near Berlin.*—Professor Beyrich has described a mass of clay, used for making tiles, within seven miles of the gates of Berlin, near the village of Hermsdorf, rising up from beneath the sands with which that country is chiefly overspread. This clay is more than forty feet thick, of a dark bluish-grey colour, and, like that of Rupelmonde, contains septaria. Among other shells the *Leda Deshayesiana*, before mentioned (fig. 156), abounds, together with many species of *Pleurotoma*, *Voluta*, &c., a certain proportion of the fossils being identical in species with those of Rupelmonde.

Mayence basin.—An elaborate description has been published by Dr. F. Sandberger of the Mayence tertiary area, which occupies a tract from five to twelve miles in breadth, extending

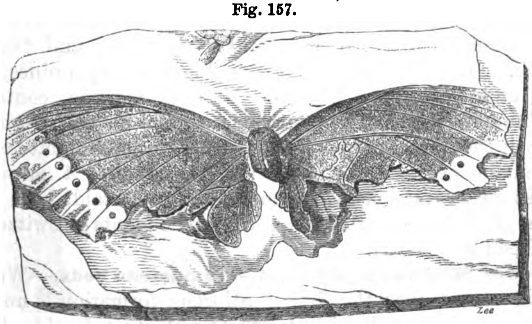
[6] D'Archiac, Monogr., pp. 79, 100.

for a great distance along the left bank of the Rhine from Mayence to the neighbourhood of Mannheim, and which is also found to the east, north, and south-west of Frankfort. M. de Koninck, of Liége, first pointed out to me that the purely marine portion of the deposit contained many species of shells common to the Kleyn Spawen beds, and to the clay of Rupelmonde, near Antwerp. Among these he mentioned *Cassidaria depressa*, *Tritonium argutum*, Brander (*T. flandricum*, De Koninck), *Tornatella simulata*, *Aporrhais Sowerbyi*, *Leda Deshayesiana* (fig. 156), *Corbula pisum* (fig. 158, p. 227), and others.

Lower Miocene beds of Croatia.—The Brown Coal of Radaboj, near Agram, in Croatia, not far from the borders of Styria, is covered, says Von Buch, by beds containing the marine shells of the Vienna basin, or, in other words, by Upper Miocene or Falunian strata. They appear to correspond in age to the Mayence basin, or to the Rupelian strata of Belgium. They have yielded more than 200 species of fossil plants, described by the late Professor Unger. These plants are well preserved in a hard marlstone, and contain several palms; among them the Sabal (fig. 151, p. 219), and another genus allied to the date-palm, *Phœnicites spectabilis*. The only abundant plant among the Radaboj fossils which is characteristic of the Upper Miocene period is the *Populus mutabilis*, whereas no less than fifty of the Radaboj species are common to the more ancient flora of the Lower Molasse of Switzerland.

The insect fauna is very rich, and, like the plants, indicates a

Fig. 157.



Vanessa Pluto; nat. size. Lower Miocene, Radaboj, Croatia.

more tropical climate than do the fossils of Œningen presently to be mentioned. There are ten species of Termites, or white ants, some of gigantic size, and large dragon-flies with speckled wings, like those of the Southern States in North America;

there are also grasshoppers of considerable size, and even the Lepidoptera are not unrepresented. In one instance, the pattern of a butterfly's wing has escaped obliteration in the marlstone of Radaboj; and when we reflect on the remoteness of the time from which it has been faithfully transmitted to us, this fact may inspire the reader with some confidence as to the reliable nature of the characters which other insects of a more durable texture, such as the beetles, may afford for specific determination. The Vanessa (fig. 157) retains, says Heer, some of its colours, and corresponds with *V. Hadena* of India.

Professor Beyrich has made known to us the existence of a long succession of marine strata in North Germany, which lead by an almost gradual transition from beds of Upper Miocene age to others of the age of the base of the Lower Miocene. Although some of the German lignites called Brown Coal belong to the upper parts of this series, the most important of them are of Lower Miocene date, as for example, those of the Siebengebirge, near Bonn, which are associated with volcanic rocks. Professor Beyrich confines the term 'Miocene' to those strata which agree in age with the faluns of Touraine, and he has proposed the term 'Oligocene' for those older formations called Lower Miocene in this work.

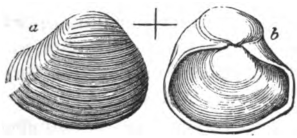
Lower Miocene of Italy.—In the hills of which the Superga forms a part (see above, p. 208) there is a great series of Tertiary strata which pass downwards into the Lower Miocene. Even in the Superga itself there are some fossil plants which, according to Heer, have never been found in Switzerland so high as the marine Molasse, such as *Banksia longifolia* and *Carpinus grandis*. In several parts of the Ligurian Apennines, as at Dégo and Carcare, the Lower Miocene appears, containing some nummulites, and at Cadibona, north of Savona, freshwater strata of the same age occur, with dense beds of lignite enclosing remains of the *Anthracotherium magnum* and *A. minimum*, besides other mammalia enumerated by Gastaldi. In these beds a great number of the Lower Miocene plants of Switzerland have been discovered.

Lower Miocene of England—Hempstead beds.—We have already stated that the Upper Miocene formation is nowhere represented in the British Isles; but strata referable to the Lower Miocene period are found both in England, Scotland, and Ireland. In the Hampshire basin these occupy a very small superficial area, having been discovered by the late Edward Forbes at Hempstead near Yarmouth, in the northern part of the Isle of Wight, where they are 170 feet thick, and

rich in characteristic marine shells. They overlie the uppermost of an extensive series of Eocene deposits of marine, brackish, and freshwater formations, which rest on the Chalk and terminate upwards in strata corresponding in age to the Paris gypsum, and containing the same extinct genera of quadrupeds, *Palæotherium*, *Anoplotherium*, and others which Cuvier first described. The following is the succession of these Lower Miocene strata, most of them exposed in a cliff east of Yarmouth.

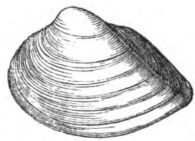
1. The uppermost or Corbula beds, consisting of marine sands and clays, contain *Voluta Rathieri*, a characteristic Lower Miocene shell; *Corbula pisum* (fig. 158), a species common to the Upper Eocene clay of Barton; *Cyrena semistriata* (fig. 159), several *Cerithia*, and other shells peculiar to this series.

Fig. 158.



Corbula pisum. Hempstead Beds, Isle of Wight.

Fig. 159.



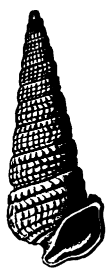
Cyrena semistriata, ½. Hempstead Beds.

2. Next below are freshwater and estuary marls and carbonaceous clays, in the brackish-water portion of which are found abundantly *Cerithium plicatum*, Lam. (fig. 160), *C. elegans* (fig. 161), and *C. tricinctum*; also *Rissoa Chastelii* (fig. 162), a very

Fig. 160.

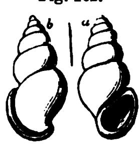
Cerithium plicatum, Lam., nat. size. Hempstead.

Fig. 161.



Cerithium elegans, nat. size. Hempstead.

Fig. 162.



Rissoa Chastelii, Nyst. Sp. Hempstead, Isle of Wight.

Fig. 163.

Paludina lenta, ½. Hempstead Beds.

common Kleyn Spawen shell, which occurs in each of the four subdivisions of the Hempstead series down to its base, where it passes into the Bembridge beds. In the freshwater

portion of the same beds *Paludina lenta* (fig. 163) occurs; a shell identified by some conchologists with a species now living; *P. unicolor*; also several species of *Limnæus, Planorbis*, and *Unio.*

3. The next series, or middle freshwater and estuary marls, are distinguished by the presence of *Melania fasciata, Paludina lenta*, and clays with *Cypris*; the lowest bed contains *Cyrena semistriata* (fig. 159), mingled with *Cerithia* and a *Panopæa.*

4. The lower freshwater and estuary marls contain *Melania costata*, Sow., *Melanopsis*, &c. The bottom bed is carbonaceous, and called the 'Black band,' in which *Rissoa Chastelii* (fig. 162) before alluded to is common. This bed contains a mixture of Hempstead shells with those of the underlying Upper Eocene or Bembridge series. The mammalia, among which is *Hyopotamus bovinus*, differ, so far as they are known, from those of the Bembridge beds. The *Hyopotamus* belongs to the hog tribe, or the same family as the Anthracotherium, of which seven species, varying in size from the hippopotamus to the wild boar, have been found in Italy and other parts of Europe associated with the lignites of the Lower Miocene period.

Among the plants, Professor Heer has recognised four species common to the lignite of Bovey Tracey (a Lower Miocene formation presently to be described): namely *Sequoia Couttsiæ*, Heer; *Andromeda reticulata*, Ettingsh.; *Nelumbium (Nymphæa) Doris*, Heer; and *Carpolithes Websteri*, Brong.[7] The seed-vessels of *Chara medicaginula*, Brong., and *C. helicteres* are characteristic of the Hempstead beds generally.

Lignites and Clays of Bovey Tracey, Devonshire.—Surrounded by the granite and other rocks of the Dartmoor hill in Devonshire, is a formation of clay, sand, and lignite, long known to geologists as the Bovey Coal formation, respecting the age of which, until the year 1861, opinions were very unsettled. This deposit is situated at Bovey Tracey, a village distant eleven miles from Exeter in a south-west, and about as far from Torquay in a north-west, direction. The strata extend over a plain nine miles long, and they consist of the materials of decomposed and worn-down granite mixed with vegetable matter, and have evidently filled up an ancient hollow or lake-like expansion of the valleys of the Bovey and Teign.

The lignite is of bad quality for economical purposes, having a great admixture of iron pyrites, and emitting a sulphurous odour; it has, however, been successfully applied to the baking

[7] Pengelly, preface to 'The Lignite Formation of Bovey Tracey,' p. xvii.; London 1863.

of pottery, for which some of the fine clays are well adapted. Mr. Pengelly has confirmed Sir H. De la Beche's opinion that much of the upper portion of this old lacustrine formation has been removed by denudation.[8]

At the surface is a dense covering of white clay and gravel with angular stones probably of the Pleistocene period, for in the clay are three species of willow and the dwarf birch, *Betula nana*, indicating a climate colder than that of Devonshire at the present day.

Below this are Lower Miocene strata about 300 feet in thickness, in the upper part of which are twenty-six beds of lignite, clay, and sand, and at their base a ferruginous quartzose sand, varying in thickness from two to twenty-seven feet. Below this sand are forty-five beds of alternating lignite and clay. No shells or bones of mammalia, and no insect, with the exception of one fragment of a beetle (*Bupestris*) ; in a word, no organic remains, except plants, have as yet been found. These plants occur in fourteen of the beds ; namely, in two of the clays, and the rest in the lignites. One of the beds is a perfect mat of the *débris* of a coniferous tree, called by Heer *Sequoia Couttsiæ*, intermixed with leaves of ferns. The same Sequoia (before mentioned as a Hempstead fossil, is spread through all parts of the formation, its cones, and seeds, and branches of every age being preserved. It is a species supplying a link between *S. Langsdorfii* (see fig. 153, p. 220) and *S. Sternbergi*, the widely spread fossil representatives of the two living trees *S. sempervirens* and *S. gigantea* (or Wellingtonia), both now confined to California. Another bed is full of the large rhizomes of ferns, while two others are rich in dicotyledonous leaves. In all Professor Heer enumerates forty-nine species of plants, twenty of which are common to the Miocene beds of the Continent, a majority of them being characteristic of the Lower Miocene. The new species, also of Bovey, are allied to plants of the older Miocene deposits of Switzerland, Germany, and other Continental countries. The grape-stones of two species of vine occur in the clays, and leaves of the fig, and seeds of a water-lily. The oak and laurel have supplied many leaves. Of the triple-nerved laurels several are referred to Cinnamomum. There are leaves also of a palm of which the genus is not determined. Leaves also of protaceous forms, like some of the Continental fossils before mentioned, occur, and ferns like the well-known *Lastræa stiriaca* (fig. 154, p. 220), displaying at Bovey as in Switzerland its fructification.

[8] Phil. Trans., 1863. Paper by W. Pengelly, F.R.S., and Dr. Oswald Heer.

The croziers of some of the young ferns are very perfect, and were at first mistaken by collectors for shells of the genus *Planorbis*. On the whole, the vegetation of Bovey implies the existence of a sub-tropical climate in Devonshire, in the Lower Miocene period.

Scotland.—Isle of Mull.—In the sea-cliffs, forming the headland of Ardtun, on the west coast of Mull, in the Hebrides, several bands of tertiary strata containing leaves of dicotyledonous plants were discovered in 1851 by the Duke of Argyll.[9] From his description it appears that there are three leaf-beds, varying in thickness from 1½ to 2½ feet, which are interstratified with volcanic tuff and trap, the whole mass being about 130 feet in thickness. A sheet of basalt 40 feet thick covers the whole; and another columnar bed of the same rock, 10 feet thick, is exposed at the bottom of the cliff. One of the leaf-beds consists of a compressed mass of leaves unaccompanied by any stems, as if they had been blown into a marsh where a species of *Equisetum* grew, of which the remains are plentifully embedded in clay.

It is supposed by the Duke of Argyll that this formation was accumulated in a shallow lake or marsh in the neighbourhood of a volcano, which emitted showers of ashes and streams of lava. The tufaceous envelope of the fossils may have fallen into the lake from the air as volcanic dust, or have been washed down into it as mud from the adjoining land. Even without the aid of Tertiary fossil plants, we might have decided that the deposit was newer than the chalk, for chalk flints containing cretaceous fossils were detected by the Duke in the principal mass of volcanic ashes or tuff.[1]

The late Edward Forbes observed that some of the plants of this formation resembled those of Croatia, described by Unger; and his opinion has been confirmed by Professor Heer, who found that the conifer most prevalent was the *Sequoia Langsdorffi* (fig. 153, p. 220), also *Corylus grosse-dentata*, a Lower Miocene species of Switzerland and of Menat, in Auvergne. There is likewise a plane tree, the leaves of which seem to agree with those of *Platanus aceroides* (fig. 141, p. 203), and a fern, *Filicites hebridica*, Forbes, which is as yet peculiar as a European fossil to Mull, but which is considered by Newberry to be identical with a living American species, *Onoclea sensibilis*.

These interesting discoveries in Mull led geologists to suspect that the basalt of Antrim and of the Giant's Causeway, in

[9] Quart. Geol. Journal, 1851, p. 19.
[1] Ibid. p. 90.

Ireland, might be of the same age. The volcanic rocks that overlie the chalk, and some of the strata associated with and interstratified between masses of basalt, contain leaves of dicotyledonous plants, somewhat imperfect, but resembling the beech, oak, and plane, and also some coniferæ of the genera pine and Sequoia. The general dearth of strata in the British Isles, intermediate in age between the formation of the Eocene and Pliocene periods, may arise, says Professor Forbes, from the extent of dry land which prevailed in that vast interval of time. If land predominated, the only monuments we are likely ever to find of Miocene date are those of lacustrine and volcanic origin, such as the Bovey Coal in Devonshire, the Ardtun beds in Mull, or the lignites and associated basalts in Antrim.

Lower Miocene, United States.—*Nebraska.*—In the territory of Nebraska, on the Upper Missouri, near the Platte River, lat. 42° N., a Tertiary formation occurs, consisting of white limestone, marls, and siliceous clay, described by Dr. D. Dale Owen,[2] in which many bones of extinct quadrupeds, and of chelonians of land or freshwater forms, are met with. Among these, Dr. Leidy describes a gigantic quadruped, called by him *Titanotherium*, nearly allied to the *Palæotherium*, but larger than any of the species found in the Paris gypsum. With these are several species of the genus *Oreodon*, Leidy, uniting the characters of pachyderms and ruminants; *Eucrotaphus*, another new genus of the same mixed character; two species of rhinoceros of the sub-genus *Acerotherium*, a Lower Miocene form of Europe before mentioned; two species of *Archæotherium*, a pachyderm allied to *Chæropotamus* and *Hyracotherium*; also *Pœbrotherium*, an extinct ruminant allied to *Dorcatherium*, Kaup; also *Agriochœrus* of Leidy, a ruminant allied to *Merycopotamus* of Falconer and Cautley; and, lastly, a large carnivorous animal of the genus *Machairodus*, the most ancient example of which in Europe occurs in the Lower Miocene strata of Auvergne, but of which some species are found in Pliocene deposits; and one species even survived in Palæolithic times, occurring in Kent's Cavern, associated with unpolished flint implements. The turtles are referred to the genus *Testudo*, but have some affinity to *Emys*. On the whole, the Nebraska formation is probably newer than the Paris gypsum, and referable to the Lower Miocene period, as above defined.

[2] David Dale Owen, Geol. Survey of Wisconsin, &c.; Philad. 1852.

CHAPTER XVI.

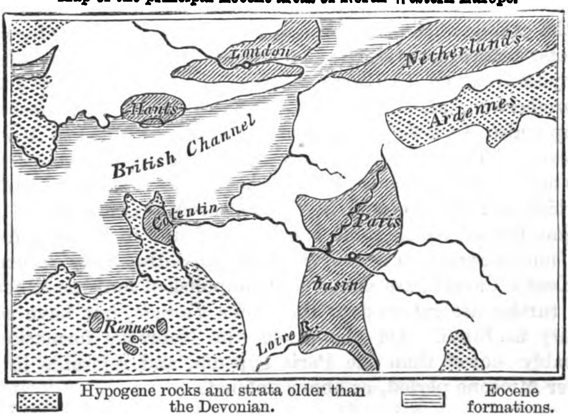
EOCENE FORMATIONS.

Eocene areas of North of Europe—Table of English and French Eocene strata—Upper Eocene of England—Bembridge beds—Osborne or St. Helen's beds—Headon series—Fossils of the Barton sands and clays—Middle Eocene of England—Shells, nummulites, fish, and reptiles of the Bracklesham beds and Bagshot sands—Plants of Alum Bay and Bournemouth—Lower Eocene of England—London Clay fossils—Woolwich and Reading beds formerly called 'Plastic Clay'—Fluviatile beds underlying deep-sea strata—Thanet sands—Upper Eocene strata of France—Gypseous series of Montmartre and extinct quadrupeds—Fossil footprints in Paris gypsum—Imperfection of the Record—Calcaire siliceux—Grès de Beauchamp—Calcaire grossier—Miliolite limestone—Soissonais sands—Lower Eocene of France—Nummulitic formations of Europe, Africa, and Asia—Eocene strata in United States—Gigantic cetacean.

Eocene areas of the North of Europe.—The strata next in order in the descending series are those which I term Eocene.

Fig. 164.

Map of the principal Eocene areas of North-Western Europe.



N.B. The space left blank is occupied by fossiliferous formations from the Devonian to the chalk inclusive.

In the accompanying map, the position of several Eocene areas in the North of Europe is pointed out. When this map was

constructed I classed as the newer part of the Eocene those Tertiary strata which have been described in the last chapter as Lower Miocene, and to which M. Beyrich has given the name of Oligocene. None of these occur in the London Basin, and they occupy in that of Hampshire, as we have seen at p. 227, too insignificant a superficial area to be noticed in a map on this scale. They fill a larger space in the Paris Basin between the Seine and the Loire, and constitute also a part of the northern limits of the area of the Netherlands which are shaded in the map.

It is in the northern part of the Isle of Wight that we have the uppermost beds of the true Eocene best exhibited, namely, those which correspond in their fossils with the celebrated gypsum of the Paris Basin before alluded to, p. 213 (see Table, p. 234). This gypsum has been selected by almost all Continental geologists as affording the best line of demarcation between the Middle and Lower Tertiary, or, in other words, between the Lower Miocene and Eocene formations.

In reference to the annexed table I may observe that the correlation of the French and English subdivisions here laid down is often a matter of great doubt and difficulty, notwithstanding their geographical proximity. This arises from various circumstances, partly from the former prevalence of marine conditions in one basin simultaneously with fluviatile or lacustrine in the other, and sometimes from the existence of land in one area causing a break or absence of all records during a period when deposits may have been in progress in the other basin. As bearing on this subject it may be stated that we have unquestionable evidence of oscillations of level shown by the superposition of salt or brackish-water strata to fluviatile beds; and those of deep-sea origin to strata formed in shallow water. Even if the upward and downward movements were uniform in amount and direction, which is very improbable, their effect in producing the conversion of sea into land or land into sea would be different according to the previous shape and varying elevation of the land and bottom of the sea. Lastly, denudation, marine and subaërial, has frequently caused the absence of deposits in one basin of corresponding age to those in the other, and this destructive agency has been more than ordinarily effective on account of the loose and unconsolidated nature of the sands and clays.

TABLE OF ENGLISH AND FRENCH EOCENE STRATA.

English subdivisions.	French equivalents.
UPPER EOCENE.	
A. 1. Bembridge series, Isle of Wight, p. 234.	A. 1. Gypseous series of Montmartre, p. 253.
A. 2. Osborne or St. Helen's series, Isle of Wight, p. 236.	A. 2 and 3. Calcaire siliceux, or Travertin inférieur, p. 256.
A. 3. Headon series, Isle of Wight, p. 237.	
A. 4. Barton series. Sands and clays of Barton Cliff, Hants, p. 239.	A. 4. Grès de Beauchamp, or Sables moyens, p. 256.
MIDDLE EOCENE.	
B. 1. Bracklesham series, p. 241.	B. 1. Calcaire grossier, p. 256.
B. 2. Alum Bay and Bournemouth beds, p. 244.	B. 2. Wanting in France?
B. 2. Wanting in England?	B. 2. Soissonnais sands, or Lits coquilliers, p. 258.
LOWER EOCENE.	
C. 1. London Clay, p. 246.	C. 1. Argile de Londres, Cassel, near Dunkirk.
C. 2. Woolwich and Reading series, p. 249.	C. 2. Argile plastique and lignite, p. 258.
C. 3. Thanet sands, p. 251.	C. 3. Sables de Bracheux, p. 259.

UPPER EOCENE, ENGLAND.

Bembridge series, A. 1.—These beds are about 120 feet thick, and, as before stated (p. 227), lie immediately under the Hempstead beds near Yarmouth, in the Isle of Wight, being conformable with those Lower Miocene strata. They consist of marls, clays, and limestones of freshwater, brackish, and marine origin. Some of the most abundant shells, as *Cyrena semistriata* var., and *Paludina lenta* (fig. 163, p. 227), are common to this and to the overlying Hempstead series; but the majority of the species are distinct. The following are the subdivisions described by the late Professor Forbes:—

a. Upper marls, distinguished by the abundance of *Melania turritissima*, Forbes (fig. 165).

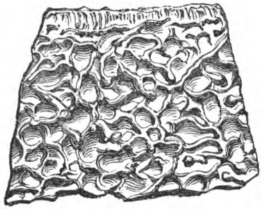
b. Lower marls, characterised by *Cerithium mutabile*, *Cyrena pulchra*, &c., and by the remains of *Trionyx* (see fig. 166).

c. Green marls, often abounding in a peculiar species of oyster, and accompanied by *Cerithium, Mytilus, Arca, Nucula,* &c.

Fig. 165.

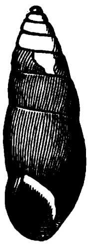
Melania turritissima, Forbes. Bembridge.

Fig. 166.



Fragment of Carapace of *Trionyx.* Bembridge Beds, Isle of Wight.

Fig. 167.

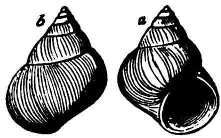


Bulimus ellipticus, Sow. Bembridge Limestone, ½ nat. size.

Fig. 168.

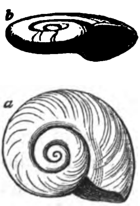
Helix occlusa, Edwards, nat. size. Bembridge Limestone, Isle of Wight.

Fig. 169.



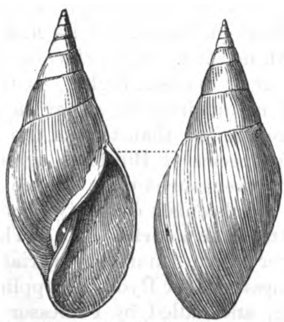
Paludina orbicularis, ½. Bembridge.

Fig. 170.



Planorbis discus, Edwards. Bembridge, ½ diam.

Fig. 171.



Limnœa fusiformis, Sow., nat. size.

Fig. 172.

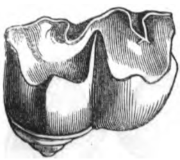
Chara tuberculata, seed-vessel, mag. Bembridge Limestone, I. of Wight.

d. Bembridge limestones, compact cream-coloured limestones alternating with shales and marls, in all of which land-shells are

common, especially at Sconce, near Yarmouth, as described by Mr. F. Edwards. The *Bulimus ellipticus* (fig. 167) and *Helix occlusa* (fig. 168) are among its best-known land shells. *Paludina orbicularis* (fig. 169) is also of frequent occurrence. One of the bands is filled with a little globular *Paludina*. Among the freshwater pulmonifera, *Limnœa fusiformis*, Sow. (fig. 171) and *Planorbis discus* (fig. 170) are the most generally distributed: the latter represents or takes the place of the *Planorbis euomphalus* (see fig. 174) of the more ancient Headon series. *Chara tuberculata* (fig. 172) is the characteristic Bembridge 'gyrogonite' or seed-vessel.

From this formation on the shores of Whitecliff Bay, Dr. Mantell obtained a fine specimen of a fan palm, *Flabellaria Lamanonis*, Brong., a plant first obtained from beds of corresponding age in the suburbs of Paris. The well-known building-stone of Binstead, near Ryde, a limestone with numerous hollows caused by *Cyrenæ* which have disappeared and left the moulds of their shells, belongs to this subdivision of the Bembridge series. In the same Binstead stone Mr. Pratt and the Rev. Darwin Fox first discovered the remains of mammalia characteristic of the gypseous series of Paris, as *Palæotherium magnum*, *P. medium*, *P. minus*, *P. minimum*, *P. curtum*, *P. crassum*; also *Anoplotherium commune* (fig. 173), *A. secundarium*, *Dichobune cervinum*, and *Chæropotamus Cuvieri*. The Paleothere, above alluded to, resembled the living tapir in the form of the head, and in having a short proboscis, but its molar teeth were more like those of the rhinoceros. *Palæotherium magnum* was of the size of a horse, four or five feet high. As the vertical range of particular species of quadrupeds, so far as our knowledge extends, is far more limited than that of the testacea, the occurrence of so many species at Binstead, agreeing with fossils of the Paris gypsum, strengthens the evidence derived from shells and plants of the synchronism of the two formations.

Fig. 173.

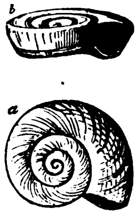


Lower molar tooth, nat. size. *Anoplotherium commune.* Binstead, Isle of Wight.

Osborne or St. Helen's series, A. 2.—This group is of fresh and brackish-water origin, and very variable in mineral character and thickness. Near Ryde, it supplies a freestone much used for building, and called by Professor Forbes the Nettlestone grit. In one part ripple-marked flag-stones occur, and rocks with fucoidal markings. The Osborne beds are distinguished by peculiar species of *Paludina*, *Melania*, and *Melanopsis*, as also of *Cypris* and the seeds of *Chara*.

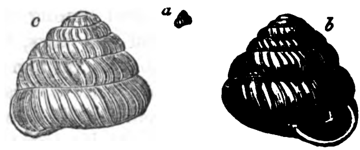
Headon series, A. 3.—These beds are seen both in Whitecliff Bay, Headon Hill, and Alum Bay, or at the east and west extremities of the Isle of Wight. The upper and lower portions are freshwater, and the middle of mixed origin, sometimes brackish and marine. Everywhere *Planorbis euomphalus* (fig. 174) characterises the freshwater deposits, just as the allied form, *P. discus* (fig. 170) does the Bembridge limestone. The

Fig. 174.



Planorbis euomphalus, Sow.
Headon Hill, ½ diam.

Fig. 175.



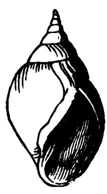
Helix labyrinthica, Say., Headon Hill, Isle of Wight; and Hordwell Cliff, Hants—also recent.

brackish-water beds contain *Potamomya plana*, *Cerithium mutabile*, and *Potamides cinctus* (fig. 37, p. 32), and the marine beds *Venus* (or *Cytherea*) *incrassata*, a species common to the Limburg beds and Grès de Fontainebleau, or the Lower Miocene

Fig. 176.

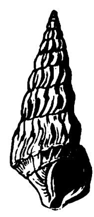
Neritina concava, Sow., nat. size. Headon series.

Fig. 177.



Limnœa caudata, Edw., ½. Headon series.

Fig. 178.



Cerithium concavum, Sow., ⅔. Headon series.

series. The prevalence of marine species is most conspicuous in some of the central parts of the formation.

Among the shells which are widely distributed through the Headon series are *Neritina concava* (fig. 176), *Limnœa caudata* (fig. 177), and *Cerithium concavum* (fig. 178). *Helix labyrinthica*, Say (fig. 175), a land-shell now inhabiting the United States, was discovered in this series by Mr. Searles Wood in Hordwell Cliff. It is also met with in Headon Hill, in the same beds. At Sconce, in the Isle of Wight, it occurs in the Bembridge series,

and affords a rare example of an Eocene fossil of a species still living, though, as usual in such cases, having no local connection with the actual geographical range of the species. The lower and middle portion of the Headon series is also met with in Hordwell Cliff (or Hordle, as it is often spelt), near Lymington, Hants. The chief shells which abound in this Cliff are *Paludina lenta* and various species of *Limnæa*, *Planorbis*, *Melania*, *Cyclas*, *Unio*, *Potamomya*, *Dreissena*, &c.

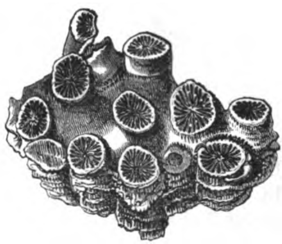
Among the chelonians we find a species of *Emys*, and no less than six species of *Trionyx*; among the saurians an alligator and a crocodile; among the ophidians two species of land-snakes (*Paleryx*, Owen); and among the fish Sir P. Egerton and Mr. Wood have found the jaws, teeth, and hard shining scales of the genus *Lepidosteus*, or bony pike of the American rivers. The same genus of freshwater ganoids has also been met with in the Hempstead beds in the Isle of Wight. The bones of several birds have been obtained from Hordwell, and the remains of quadrupeds of the genera *Palæotherium* (*P. minus*), *Anoplotherium*, *Dichodon*, *Dichobune*, *Spalacodon*, *Microchœnus*, *Lophiodon*, *Hyopotamus*, and *Hyænodon*. The latter offers, I believe, the oldest known example of a true carnivorous animal in the series of British fossils; although I attach very little theoretical importance to the fact, because herbivorous species are those most easily met with in a fossil state in all save cavern deposits. In another point of view, however, this fauna deserves notice. Its geological position is considerably lower than that of the Bembridge or Montmartre beds, from which it differs almost as much in species as it does from the still more ancient fauna of the Lower Eocene beds to be mentioned in the sequel. It therefore teaches us what a grand succession of distinct assemblages of mammalia flourished on the earth during the Eocene period.

Many of the marine shells of the brackish-water beds of the above series, both in the Isle of Wight and Hordwell Cliff, are common to the underlying Barton Clay; and on the other hand, there are some freshwater shells, such as *Cyrena obovata*, which are common to the Bembridge beds, notwithstanding the intervention of the St. Helen's series. The white and green marls of the Headon series, and some of the accompanying limestones, often resemble the Eocene strata of France in mineral character and colour in so striking a manner, as to suggest the idea that the sediment was derived from the same region or produced contemporaneously under very similar geographical circumstances.

At Brockenhurst, near Lyndhurst, in the New Forest,

marine strata have recently been found, containing 59 species of shells, many of which have been described by Mr. Edwards. These beds rest on the Lower Headon, and are considered as the equivalent of the middle part of the Headon series, many of the shells being common to the brackish-water or Middle Headon beds of Colwell and Whitecliff Bays, such as *Cancellaria muricata*, Sow., *Fusus labiatus*, Sow., &c. In these beds at Brockenhurst, corals, ably described by Dr. Duncan, have recently been found in abundance and perfection. (See fig. 179, *Solenastræa cellulosa.*)

Fig. 179.



Solenastræa cellulosa, Dunc., nat. size. Brockenhurst.

Baron von Könen[1] has pointed out that no less than 46 out of the 59 Brockenhurst shells, or a proportion of 78 per cent., agree with species occurring in Dumont's Lower Tongrian formation in Belgium. This being the case, we might fairly expect that if we had a marine equivalent of the Bembridge series or of the contemporaneous Paris gypsum, we should find it to contain a still greater number of shells common to the Tongrian beds of Belgium; but the exact correlation of these freshwater groups of France, Belgium, and Britain has not yet been fully made out. It is possible that the Tongrian of Dumont may be newer than the Bembridge series, and therefore referable to the Lower Miocene. If ever the whole series should be complete, we must be prepared to find the marine equivalent of the Bembridge beds, or the uppermost Eocene, passing by imperceptible shades into the inferior beds of the overlying Miocene strata.

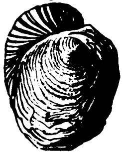
Among the fossils found in the Middle Headon are *Cytherea incrassata* and *Cerithium plicatum*, fig. 160, p. 227. These shells, especially the latter, are very characteristic of the Lower Miocene, and their occurrence in the Headon series has been cited as an objection to the line proposed to be drawn between Miocene and Eocene. But if we were to attach importance to such occasional passages, we should soon find that no lines of division could be drawn anywhere, for in the present state of our knowledge of the Tertiary series there will always be species common to beds above and below our boundary-lines.

Barton series (*Sands and Clays*), A. 4, Table, p. 234.—Both in the Isle of Wight, and in Hordwell Cliff, Hants, the Headon beds above mentioned rest on white sands usually devoid of

[1] Quart. Geol. Journal, vol. xx. p. 97. 1864.

fossils, and used in the Isle of Wight for making glass. In one of these sands Dr. Wright found *Chama squamosa*, a Barton clay shell, in great plenty, and certain impressions of marine shells have been found in sands supposed to be of the same age in Whitecliff Bay. These sands have been called Upper Bagshot in the maps of our Government Survey, but this identification of a fossiliferous series in the Isle of Wight with an unfossiliferous formation in the London Basin can scarcely be depended upon. The Barton clay, which immediately underlies these sands, is seen vertical in Alum Bay, Isle of Wight, and nearly horizontal in the cliffs of the mainland near Lymington. This clay, together with the Bracklesham beds, presently to be described, has been termed Middle Bagshot by the Survey. In Barton Cliff, where it attains a thickness of about 300 feet, it is rich in marine fossils.

Fig. 180.



Chama squamosa, Eichw., ½. Barton.

It was formerly confounded with the London Clay, an older Eocene deposit of very similar mineral character, to be mentioned in the sequel (p. 246), which contains many shells in common, but not more than one-fourth of the whole. In other words, there are known at present 247 species in the London Clay and 321 in that of Barton, and only 70 common to the two formations; 56 of these have been found in the intermediate Bracklesham beds, and the reappearance of the other 14 may imply a return of similar conditions, whether of temperature or depth or of a muddy argillaceous bottom, common to the two periods of the London and Barton clays. According to M. Hebert, the most characteristic Barton Clay fossils correspond to those of the Grès de Beauchamp, or Sables moyens, of the Paris Basin, but it also contains many common to the older Calcaire grossier.

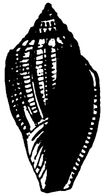
SHELLS OF THE BARTON CLAY.

Certain foraminifera called Nummulites begin, when we study the Tertiary formations in a descending order, to make their first appearance in these beds. A small species called *Nummulites variolaria* (fig. 189) is found both on the Hampshire coast and in beds of the same age in Whitecliff Bay, in the Isle of Wight. Several marine shells, among which is *Corbula pisum* (fig. 158, p. 227), are common to the Barton beds and the Hempstead or Lower Miocene series, and a still greater number, as before stated, are common to the Headon series.

Fig. 181.

Mitra scabra, Sow., nat. size.

Fig. 182.



Voluta ambigua, Sol., $\frac{1}{2}$.

Fig. 183.

Typhis pungens, Brand., nat. size.

Fig. 184.

Voluta athleta, Sol., $\frac{1}{2}$. Barton and Bracklesham.

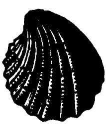
Fig. 185.

Terebellum fusiforme, Lam., nat. size. Barton and Bracklesham.

Fig. 186.

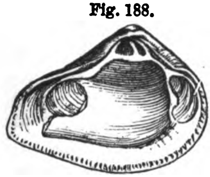
Terebellum sopita, Brand.

Fig. 187.



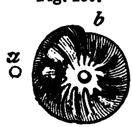
Cardita sulcata, Brand., $\frac{3}{8}$. Barton.

Fig. 188.



Crassatella sulcata, Sow., $\frac{1}{2}$. Bracklesham and Barton.

Fig. 189.



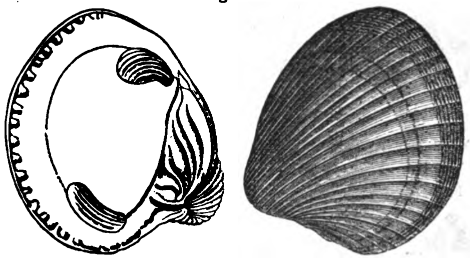
Nummulites variolaria. Lam. Var. of *N. radiata*, Sow. Mid. Eocene, Bracklesham Bay.
a. Nat. size. *b*. Magnified.

MIDDLE EOCENE, ENGLAND.

Bracklesham Beds and Bagshot Sands (B. 1, Table, p. 234).—Beneath the Barton Clay we find in the north of the Isle of Wight, both in Alum and Whitecliff Bays, a great series of various-coloured sands and clays for the most part unfossiliferous, and probably of estuarine origin. As some of these beds contain *Cardita planicosta* (fig. 190) they have been identified with the marine beds much richer in fossils seen in the coast section in Bracklesham Bay, near Chichester in Sussex, where the strata

consist chiefly of green clayey sands with some lignite. Among the Bracklesham fossils, besides the Cardita, occurs the huge *Cerithium giganteum*, so conspicuous in the Calcaire Grossier of

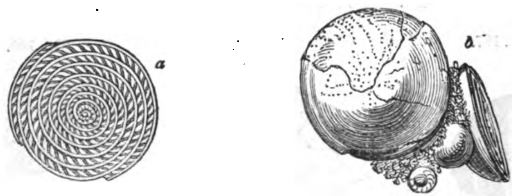
Fig. 190.



Cardita (Venericardia) planicosta, Lam., ½.

Paris, where it is sometimes two feet in length. *Nummulites lævigata* (see fig. 191), so characteristic of the lower beds of the Calcaire Grossier in France, where it sometimes forms stony layers, as near Compiègne, is also very common in these beds,

Fig. 191.



Nummulites (Nummularia) lævigata. Bracklesham. Dixon's Fossils of Sussex, Pl. 8, nat. size.

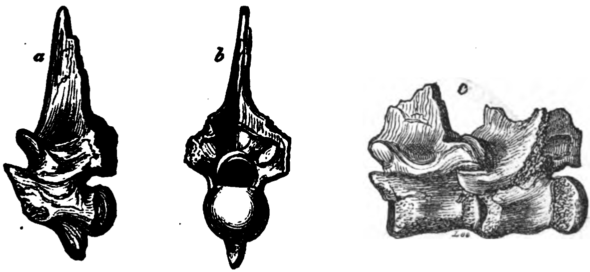
a. Section of the nummulite.
b. Group, with an individual showing the exterior of the shell.

together with *N. scabra* and *N. variolaria*. Out of 193 species of testacea procured from the Bagshot and Bracklesham beds in England, 126 occur in the Calcaire Grossier in France. It was clearly, therefore, coeval with that part of the Parisian series more nearly than with any other.

According to tables compiled from the best authorities by Mr. Etheridge, the number of mollusca now known from the Bracklesham beds in Great Britain is 393, of which no less than 240 are peculiar to this subdivision of the British Eocene series, while 70 are common to the Older London Clay, and 140 to the

Newer Barton Clay. The volutes and cowries of this formation, as well as the polyzoa and corals, favour the idea of a warm

Fig. 192.



Palæophis typhœus, Owen, ½; an Eocene sea-serpent. Bracklesham.

a, b. Vertebra, with long neural spine preserved.
c. Two vertebræ articulated together.

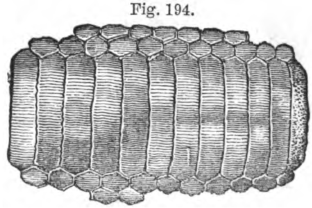
climate having prevailed, which is borne out by the discovery of the remains of a serpent, *Palæophis typhœus* (see fig. 192),

Fig. 193.

Defensive spine of Ostraceon, ⅓. Bracklesham.

exceeding, according to Professor Owen, twenty feet in length, and allied in its osteology to the Boa, Python, Coluber, and Hydrus. The compressed form and diminutive size of certain caudal vertebræ indicate so much analogy with Hydrus as to induce Professor Owen to pronounce this extinct ophidian to have been marine.[2] Amongst the companions of the sea-snake of Bracklesham was an extinct crocodile (*Gavialis Dixoni*, Owen), and numerous fish, such as now frequent the seas of warm latitudes, as the Ostraceon of the family Balistidæ, of which a dorsal spine is

Fig. 194.



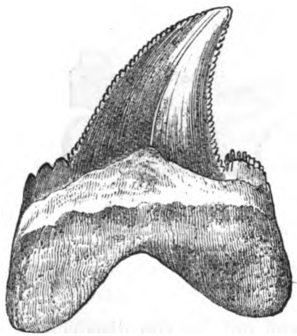
Palatal or dental plates of *Myliobates Edwardsi*, ½. Bracklesham Bay. Dixon's Fossils of Sussex, Pl. 8.

[2] Paleont. Soc. Monograph. Rept., pt. ii. p. 61.

figured (see fig. 193),[3] and gigantic rays of the genus *Myliobates* (see fig. 194).

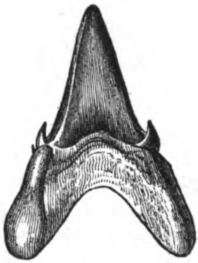
The teeth of sharks also, of the genera *Carcharodon*, *Otodus*, *Lamna*, *Galeocerdo*, and others, are abundant. (See figs. 195, 196, 197, 198.)

Fig. 195.



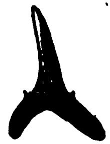
Carcharodon angustidens, Agass.

Fig. 196.



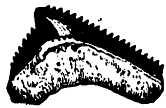
Otodus obliquus, Agass., nat. size.

Fig. 197.



Lamna elegans, Agass., nat. size.

Fig. 198.



Galeocerdo latidens, Agass., nat. size.

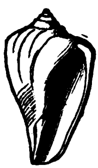
Teeth of Sharks from Bracklesham Beds.

Marine Shells of Bracklesham Beds.

Fig. 199.

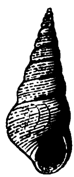
Pleurotoma attenuata, Sow., ½.

Fig. 200.



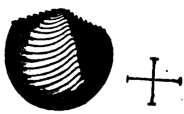
Voluta Selseiensis, Edwards, ½.

Fig. 201.



Turritella multisulcata, Lam., ½.

Fig. 202.



Lucina serrata, Sow. Magnified.

Fig. 203.

Conus deperditus, Brug., ⅓.

Alum Bay and Bournemouth beds (*Lower Bagshot of English Survey*), B. 2, Table, p. 234.—To that great series of sands and clays which intervene between the equivalents of the Bracklesham Beds and the London Clay or Lower Eocene, our Government Survey has given the name of the Lower Bagshot sands, for they are supposed to agree in age with the inferior

[3] For a description of this spine see W. C. Williamson, Phil. Trans. pt. ii. 1851, p. 667.

unfossiliferous sands of the country round Bagshot in the London Basin. This part of the series is finely exposed in the vertical beds of Alum Bay in the Isle of Wight, and east and west of Bournemouth on the south coast of Hampshire. In some of the close and white compact clays of this locality, there are not only dicotyledonous leaves, but numerous fronds of ferns allied to Gleichenia which are well preserved with their fruit.

None of the beds are of great horizontal extent, and there is much cross-stratification or false-bedding in the sands, and in some places black carbonaceous seams and lignite. In the midst of a leaf-bed at the base of the Bournemouth strata in Studland Bay, Dorsetshire, shells of the genus Unio attest the freshwater origin of the white clay.

No less than 40 species of plants are mentioned by MM. De la Harpe and Gaudin from this formation in Hampshire, among which the Proteaceæ (*Dryandra*, &c.) and the fig tribe are abundant, as well as the cinnamon and several other laurineæ, with some papilionaceous plants. On the whole they remind the botanist of the types of subtropical India and Australia.[4]

Heer has mentioned several species which are common to this Alum Bay flora and that of Monte Bolca, near Verona, so celebrated for its fossil fish, and where the strata contain nummulites and other Middle Eocene fossils. He has particularly alluded to *Aralia primigenia* (of which genus a fruit has since been found by Mr. Mitchell at Bournemouth), *Daphnogene Veronensis*, and *Ficus granadilla*, as among the species common to and characteristic of the Isle of Wight and Italian Eocene beds; and he observes that in the flora of this period those forms of a temperate climate which constitute a marked feature in the European Miocene formations, such as the willow, poplar, birch, alder, elm, hornbeam, oak, fir, and pine, are wanting. The American types are also absent, or much more feebly represented than in the Miocene period, although fine specimens of the fan-palm (*Sabal*) have been found in these Eocene clays at Studland. The number of exotic forms which are common to the Eocene and Miocene strata of Europe, like those to be alluded to in the sequel which are common to the Eocene and Cretaceous fauna, demonstrate the remoteness of the times in which the geographical distribution of living plants originated. A great majority of the Eocene genera have disappeared from our temperate climates, but not the whole of them; and they must all have exerted some influence on the assemblages of species which succeeded them. Many of these last occurring in the Upper

[4] Heer, Climat et Végétation du Pays Tertiaire, p. 172.

Miocene are indeed so closely allied to the flora now surviving as to make it questionable, even in the opinion of naturalists opposed to the doctrine of transmutation, whether they are not genealogically related the one to the other.

LOWER EOCENE FORMATIONS, ENGLAND.

London Clay (C. 1, Table, p. 234).—This formation underlies the preceding, and sometimes attains a thickness of 500 feet. It consists of tenacious brown and bluish-gray clay, with layers of concretions called septaria, which abound chiefly in the brown clay, and are obtained in sufficient numbers from sea-cliffs near Harwich, and from shoals off the coast of Essex and the Isle of Sheppey, to be used for making Roman cement. The total number of British fossil mollusca known at present (January 1870) in this formation are 266, of which 160 are peculiar, or not found in other Eocene beds in this country. The principal localities of fossils in the London clay are Highgate Hill, near London, the island of Sheppey at the mouth of the Thames, and Bognor on the Sussex coast. Out of 133 fossil shells, Mr. Prestwich found only 20 to be common to the Calcaire Grossier (from which 600 species have been obtained), while 33 are common to the 'Lits Coquilliers' (p. 258), in which 200 species are known in France.

In the island of Sheppey, near the mouth of the Thames, the thickness of the London Clay is estimated by Mr. Prestwich to be more than 500 feet; and it is in the uppermost 50 feet that a great number of fossil fruits were obtained, being chiefly found on the beach when the sea has washed away the clay of the rapidly wasting cliffs.

Fig. 204.

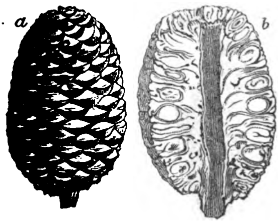
Nipadites ellipticus, Bow., ½. Fossil fruit of palm, from Sheppey.

Mr. Bowerbank, in a valuable publication on these fossil fruits and seeds, has described no less than thirteen fruits of palms of the recent type *Nipa*, now only found in the Molucca and Philippine Islands, and in Bengal (see fig. 204). In the delta of the Ganges, Sir J. Hooker observed the large nuts of *Nipa fruticans* floating in such numbers in the various arms of that great river, as to obstruct the paddle-wheels of steam-boats. These plants are allied to the cocoa-nut tribe on the one side, and on the other to the *Pandanus*, or screwpine. There are also met with three species of *Anona*, or custard apple; and

cucurbitaceous fruits (of the gourd and melon family), and fruits of various species of *Acacia*.

Besides fir-cones or fruit of true Coniferæ there are cones of Proteaceæ in abundance, and the celebrated botanist the late Robert Brown pointed out the affinity of these to the New Holland types *Petrophila* and *Isopogon*. Of the first there are about 50 and the second 30 described species now living in Australia.

Fig. 205.



Eocene Proteaceous Fruit.
Petrophiloides Richardsoni, London Clay, Sheppey. Natural size.
a. Cone. *b*. Section of cone showing the position of the seeds.

Ettingshausen remarked in 1851 that five of the fossil species from Sheppey, named by Bowerbank,[5] were specimens of the same fruit (see fig. 205) in different states of preservation; and Mr. Carruthers, having examined the original specimens now in the British Museum, tells me that all these cones from Sheppey may be reduced to two species, which have an undoubted affinity to the two existing Australian genera above mentioned, although their perfect identity in structure cannot be made out.

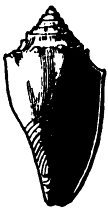
The contiguity of land may be inferred not only from these vegetable productions, but also from the teeth and bones of crocodiles and turtles, since these creatures, as Dean Conybeare remarked, must have resorted to some shore to lay their eggs. Of turtles there were numerous species referred to extinct genera. These are, for the most part, not equal in size to the largest living tropical turtles. A sea-snake, which must have been thirteen feet long, of the genus *Palæophis* before mentioned (p. 243), has also been described by Professor Owen from Sheppey, of a different species from that of Bracklesham, and called *P. toliapicus*. A true crocodile, also, *Crocodilus toliapicus*, and another saurian more nearly allied to the gavial, accompany the above fossils; also the relics of several birds and quadrupeds. One of these last belongs to the new genus *Hyracotherium* of Owen, of the hog tribe, allied to Chæropotamus; another is a *Lophiodon*; a third a pachyderm called *Coryphodon eocænus* by Owen, larger than any existing tapir. All these animals seem to have inhabited the banks of the great river which floated down the Sheppey fruits. They imply the existence of a mammiferous fauna antecedent to the period when nummulites flourished in Europe and Asia, and therefore before the Alps, Pyrenees,

[5] Bowerbank, Fossil Fruits and Seeds of London Clay, Plates ix. and x.

and other mountain-chains now forming the back-bones of great continents, were raised from the deep; nay, even before a part of the constituent rocky masses now entering into the central ridges of these chains had been deposited in the sea.

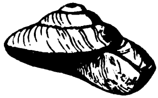
SHELLS OF THE LONDON CLAY.

Fig. 206.



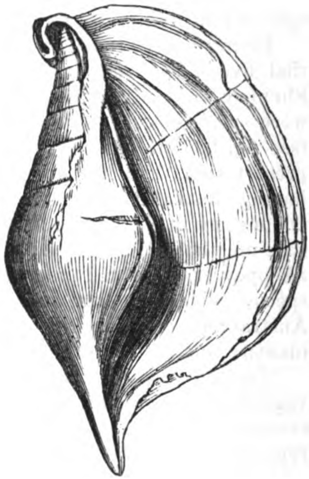
Voluta nodosa, Sow., ½. Highgate.

Fig. 207.



Phorus extensus, Sow., ½. Highgate.

Fig. 208.



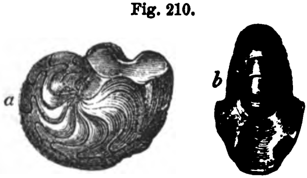
Rostellaria (*Hippocrenes*) *ampla*, Brander, ⅓ of nat. size; also found in the Barton clay.

Fig. 209.

Nautilus centralis, Sow., ⅓. Highgate.

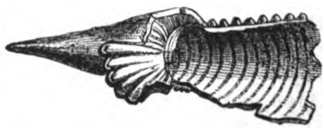
The marine shells of the London clay confirm the inference derivable from the plants and reptiles in favour of a high temperature. Thus many species of *Conus* and *Voluta* occur, a large

Fig. 210.



Aturia ziczac, Bronn., Syn. *Nautilus ziczac*, Sow. London clay. Sheppey. ⅔.

Fig. 211.

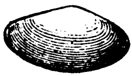


Belosepia sepioidea, De Blainv., nat. size, London clay. Sheppey.

Cypræa, *C. oviformis*, a very large *Rostellaria* (fig. 208), a species of *Cancellaria*, six species of *Nautilus* (fig. 210), besides other Cephalopoda of extinct genera, one of the most remarkable of

which is the *Belosepia* (fig. 211). Among many characteristic bivalve shells are *Leda amygdaloides* (fig. 212) and *Cryptodon angulatum* (fig. 213), and among the Radiata a star-fish, *Astropecten* (fig. 214).

Fig. 212.



Leda amygdaloides, Sow., $\frac{2}{3}$. Highgate.

Fig. 213.

Cryptodon (*Axinus*) *angulatum*, Sow., nat. size. London clay, Hornsey.

Fig. 214.

Astropecten crispatus, E. Forbes, $\frac{1}{3}$. Sheppey.

These fossils are accompanied by a sword-fish (*Tetrapterus priscus*, Agassiz), about eight feet long, and a saw-fish (*Pristis bisulcatus*, Ag.), about ten feet in length ; genera now foreign to the British seas. On the whole, about eighty species of fish have been described by M. Agassiz from these beds of Sheppey, and they indicate, in his opinion, a warm climate.

In the lower part of the London clay at Kyson, a few miles east of Woodbridge, the remains of mammalia have been detected. Some of these have been referred by Professor Owen to an opossum, and others to the genus *Hyracotherium*. The teeth of this last-mentioned Pachyderm were at first, in 1840, supposed to belong to a monkey ; an opinion afterwards abandoned by Owen when more ample materials for comparison were obtained.

Woolwich and Reading series (C. 2, Table, p. 234).—This formation was formerly called the Plastic Clay, as it agrees with a similar clay used in pottery which occupies the same position in the French series, and it has been used for the like purposes in England.[6]

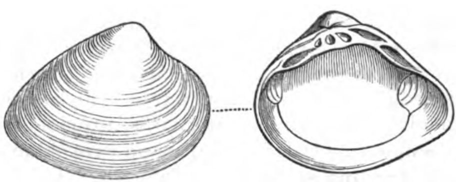
No formations can be more dissimilar on the whole in mineral character than the Eocene deposits of England and Paris ; those of our own island being almost exclusively of mechanical origin, —accumulations of mud, sand, and pebbles ; while in the neighbourhood of Paris we find a great succession of strata composed of limestones, some of them siliceous, and of crystalline gypsum and siliceous sandstone, and sometimes of pure flint used for millstones. Hence it is often impossible, as before stated, to institute an exact comparison between the various members of the English and French series, and to settle their respective ages. But in regard to the division which we have now under consideration, whether we study it in the basins of London, Hampshire, or Paris, we recognise as a general rule the

[6] Prestwich, Quart. Geol. Journ. vol. x.

same mineral character, the beds consisting over a large area of mottled clays and sand, with lignite, and with some strata of well-rolled flint pebbles, derived from the chalk, varying in size, but occasionally several inches in diameter. These strata may be seen in the Isle of Wight or at Bognor in contact with the chalk, or in the London Basin, at Reading, Blackheath, and Woolwich. In some of the lowest of them, banks of oysters are observed, consisting of *Ostrea bellovacina*, so common in France in the same relative position. In these beds at Bromley, Dr. Buckland found a large pebble to which five full-grown oysters were affixed, in such a manner as to show that they had commenced their first growth upon it, and remained attached through life.

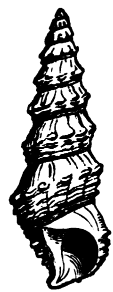
In several places, as at Woolwich on the Thames, at Newhaven in Sussex, and elsewhere, a mixture of marine and freshwater testacea distinguishes this member of the series. Among the latter, *Melania inquinata* (see fig. 216) and *Cyrena Cuneiformis*

Fig. 215.



Cyrena cuneiformis, Sow. Natural size. Woolwich clays.

Fig. 216.



Melania (Melanatria) inquinata, Def. Syn. *Cerithium melanoides*, Sow., ½. Woolwich clays.

(see fig. 215) are very common, as in beds of corresponding age in France. They clearly indicate points where rivers entered the Eocene sea. Usually there is a mixture of brackish, fresh-water, and marine shells, and sometimes, as at Woolwich, proofs of the river and the sea having successively prevailed on the same spot. At New Charlton, in the suburbs of Woolwich, Mr. De la Condamine discovered in 1849, and pointed out to me, a layer of sand associated with well-rounded flint pebbles in which numerous individuals of the *Cyrena tellinella* were seen standing endwise with both their valves united, the siphonal extremity of each shell being uppermost, as would happen if the mollusks had died in their natural position. I have described [7] a bank of

[7] Second Visit to the United States, vol. ii. p. 104.

sandy mud, in the delta of the Alabama River at Mobile, on the borders of the Gulf of Mexico, where in 1846 I dug out at low tide specimens of living species of *Cyrena* and of a *Gnathodon*, which were similarly placed with their shells erect, or in a posture which enables the animal to protrude its siphon upwards and draw in or reject water at pleasure. The water at Mobile is usually fresh, but sometimes brackish. At Woolwich a body of river-water must have flowed permanently into the sea where the *Cyrenæ* lived, and they may have been killed suddenly by an influx of pure salt water, which invaded the spot when the river was low, or when a subsidence of land took place. Traced in one direction, or eastward towards Herne Bay, the Woolwich beds become more sandy and assume more and more of a marine character; while in an opposite, or south-western direction, the beds are more uniformly clayey, and they become, as near Chelsea and other places, more freshwater, and contain *Unio*, *Paludina*, and layers of lignite, so that the land drained by the ancient river seems clearly to have been to the south-west of the present site of the metropolis.

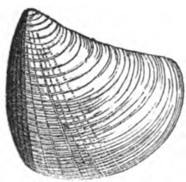
[In the upper part of this series in Kent and Surrey are interstratified enormous masses of pebbles or shingle formed of well-rounded flints. These beds have been separated by some geologists, from both the under and overlying formations, and called the 'Oldhaven beds.']

Fluviatile beds underlying deep-sea strata.—Before the minds of geologists had become familiar with the theory of the gradual sinking of land, and its conversion into sea at different periods, and the consequent change from shallow to deep water, the fluviatile and littoral character of this inferior group appeared strange and anomalous. After passing through hundreds of feet of London clay, proved by its fossils to have been deposited in deep salt water, we arrive at beds of fluviatile origin, and associated with them masses of shingle, attaining at Blackheath, near London, a thickness of 50 feet. These shingle banks are probably of marine origin, but they indicate the proximity of land, and the existence of a shore where the flints of the chalk were rolled into sand and pebbles, and spread over a wide space. We have, therefore, first as before stated (p. 250), evidence of oscillations of level during the accumulation of the Woolwich series, then of a great submergence, which allowed a marine deposit 500 feet thick to be laid over the antecedent beds of fresh and brackish water origin.

Thanet sands (C. 3, p. 234).—The Woolwich or plastic clay above described may often be seen in the Hampshire basin in actual contact with the chalk, constituting in such places the

lowest member of the British Eocene series. But at other points another formation of marine origin, characterised by a somewhat different assemblage of organic remains, has been shown by Mr. Prestwich to intervene between the chalk and the Woolwich series. For these beds he has proposed the name of 'Thanet sands,' because they are well seen in the Isle of Thanet, in the northern part of Kent, and on the sea-coast between

Fig. 217.

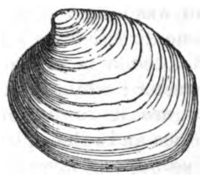


Pholadomya cuneata, Sow., ⅔. Thanet sands.

Fig. 218.

Aporrhais Sowerbyi, Mant., nat. size. Thanet sands.

Fig. 219.



Cyprina Morrisii, Sow., ½. Thanet sands.

Herne Bay and the Reculvers, where they consist of sands with a few concretionary masses of sandstone, and contain, among other fossils, *Pholadomya cuneata* (fig. 217), *Cyprina Morrisii* (fig. 219), *Corbula longirostris*, *Scalaria Bowerbankii*, *Aporrhais Sowerbyi* (fig. 218), &c. The greatest thickness of these beds is about 90 feet.

UPPER EOCENE FORMATIONS OF FRANCE.

The Tertiary formations in the neighbourhood of Paris consist of a series of marine and freshwater strata, alternating with each other, and filling up a depression in the chalk. The area which they occupy has been called the Paris Basin, and is about 180 miles in its greatest length from north to south, and about 90 miles in breadth from east to west. MM. Cuvier and Brongniart attempted, in 1810, to distinguish five different groups, comprising three freshwater and two marine, which were supposed to imply that the waters of the ocean, and of rivers and lakes, had been by turns admitted into and excluded from the same area. Investigations since made in the Hampshire and London Basins have rather tended to confirm these views, at least so far as to show that since the commencement of the Eocene period there have been great movements of the bed of the sea, and of the adjoining lands, and that the superposition of deep sea to shallow water deposits (the London clay, for example, to the Woolwich beds) can only be explained by referring

to such movements. It appears, notwithstanding, from the researches of M. Constant Prévost, that some of the minor alternations and intermixtures of freshwater and marine deposits, in the Paris Basin, may be accounted for without such changes of level, by imagining both to have been simultaneously in progress, in the same bay of the same sea, or a gulf into which many rivers entered.

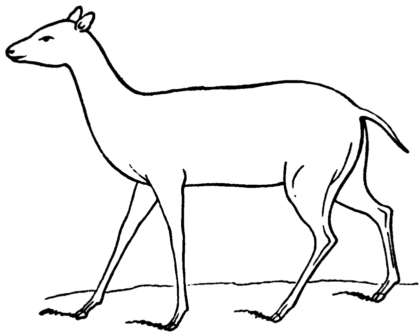
Gypseous series of Montmartre (A. 1, Table, p. 234).—To enlarge on the numerous subdivisions of the Parisian strata would lead me beyond my present limits; I shall therefore give some examples only of the most important formations. Beneath the Grès de Fontainebleau, belonging, as before stated, to the Lower Miocene period, we find, in the neighbourhood of Paris, a series of white and green marls, with subordinate beds of gypsum. These are most largely developed in the central parts of the Paris Basin, and, among other places, in the hill of Montmartre, where its fossils were first studied by Cuvier.

The gypsum quarried there for the manufacture of plaster of Paris occurs as a granular crystalline rock, and, together with the associated marls, contains land and fluviatile shells, and the bones and skeletons of birds and quadrupeds. Several land-plants are also met with, among which are fine specimens of the fan-palm or palmetto tribe (*Flabellaria*). The remains also of freshwater fish, and of crocodiles and other reptiles, occur in the gypsum. The skeletons of mammalia are usually isolated, often entire, the most delicate extremities being preserved; as if the carcases, clothed with their flesh and skin, had been floated down soon after death, and while they were still swollen by the gases generated by their first decomposition. The few accompanying shells are of those light kinds which frequently float on the surface of rivers, together with wood.

In this formation the relics of about fifty species of quadrupeds, including the genera *Palæotherium Anoplotherium*, and others, have been found, all extinct, and nearly four-fifths of them belonging to the Perissodactyle or odd-toed division of the order *Pachydermata*, which now contains only four living genera, namely, rhinoceros, tapir, horse, and hyrax. The *Anoplotheridæ* form a tribe intermediate between pachyderms and ruminants. One of the three divisions of this family was called by Cuvier *Xiphodon*. Their forms were slender and elegant, and one, named *Xiphodon gracile* (fig. 220), was about the size of the chamois; and Cuvier inferred from the skeleton that it was as light, graceful, and agile as the gazelle. With these Pachydermata are associated a few carnivorous animals, among which are the *Hyænodon dasyuroides*;

a species of dog, *Canis Parisiensis;* and a weasel, *Cynodon Parisiensis.* Of the *Rodentia* are found a squirrel; of the *Cheiroptera*, a bat; while the *Marsupialia* (an order now confined to America,

Fig. 220.



Xiphodon gracile, or *Anoplotherium gracile*, Cuvier. Restored outline.

Australia, and some contiguous islands) are represented by an opossum.

Of birds, about 17 species have been discovered, five of which are still undetermined. The skeletons of some are entire, but none are referable to existing species.[8] The same remark, according to MM. Cuvier and Agassiz, applies both to the reptiles and fish. Among the last are crocodiles and tortoises of the genera *Emys* and *Trionyx.* The tribe of land quadrupeds most abundant in this formation is such as now inhabits alluvial plains and marshes, and the banks of rivers and lakes, a class most exposed to suffer by river inundations.

Fossil footprints.—There are three superimposed masses of gypsum in the neighbourhood of Paris, separated by intervening deposits of laminated marl. In the uppermost of the three in the valley of Montmorency M. Desnoyers discovered in 1859 many footprints of animals occurring at no less than six different levels.[9] The gypsum to which they belong varies from thirty to fifty feet in thickness, and is that which has yielded to the naturalist the largest number of bones and skeletons of mammalia, birds, and reptiles. I visited the quarries, soon after the discovery was made known, with M. Desnoyers, who also showed me large slabs in the Museum at Paris, where, on the upper planes of stratification, the indented

[8] Cuvier, Oss. Foss. tom. iii. p. 255.

[9] Sur des Empreintes de Pas d'Animaux, par M. J. Desnoyers. Compte rendu de l'Institut, 1859.

footmarks were seen, while corresponding casts in relief appeared on the lower surfaces of the strata of gypsum which were immediately superimposed. A thin film of marl, which before it was dried and condensed by pressure must have represented a much thicker layer of soft mud, intervened between the beds of solid gypsum. On this mud the animals had trodden, and made impressions which had penetrated to the gypseous mass below, then evidently unconsolidated. Tracks of the *Anoplotherium*, with its bisulcate hoof, and the trilobed footprints of *Palæotherium*, were seen of different sizes, corresponding to those of several species of these genera which Cuvier had reconstructed, while in the same beds were footmarks of carnivorous mammalia. The tracks also of fluviatile, lacustrine, and terrestrial tortoises (*Emys*, *Trionyx*, &c.) were discovered; also those of crocodiles, iguanas, geckos, and great batrachians; and the footprints of a huge bird, apparently a wader, of the size of the gastornis, to be mentioned in the sequel. There were likewise impressions of the feet of other creatures, some of them clearly distinguishable from any of the fifty extinct types of mammalia, of which the bones have been found in the Paris gypsum. The whole assemblage, says Desnoyers, indicates the shores of a lake, or several small lakes communicating with each other, on the borders of which many species of Pachyderms wandered, and beasts of prey which occasionally devoured them. The toothmarks of these last had been detected by palæontologists long before on the bones and skulls of *Paleotheres* entombed in the gypsum.

Imperfection of the Record.—These footmarks have revealed to us new and unexpected proofs that the air-breathing fauna of the Upper Eocene period in Europe far surpassed in the number and variety of its species the largest estimate which had previously been formed of it. We may now feel sure that the mammalia, reptiles, and birds, which have left portions of their skeletons as memorials of their existence in the solid gypsum, constituted but a part of the then living creation. Similar inferences may be drawn from the study of the whole succession of geological records. In each district the monuments of periods embracing thousands, and probably in some instances hundreds of thousands of years, are totally wanting. Even in the volumes which are extant the greater number of the pages are missing in any given region, and where they are found they contain but few and casual entries of the physical events or living beings of the times to which they relate. It may also be remarked that the subordinate formations met with in two neighbouring countries, such as France and England, commonly

classed as equivalents and referred to corresponding periods, may nevertheless have been by no means strictly coincident in date. Though called contemporaneous, it is probable that they were often separated by intervals of many thousands of years. We may compare them to double stars, such as the polar star, which appear single to the naked eye because seen from a vast distance in space, and which really belong to one and the same stellar system, though occupying places in space extremely remote if estimated by our ordinary standard of terrestrial measurements.

Calcaire siliceux, or Travertin inférieur (A. 2 and 3, Table, p. 234).—This compact siliceous limestone extends over a wide area. It resembles a precipitate from the waters of mineral springs, and is often traversed by small empty sinuous cavities. It is, for the most part, devoid of organic remains, but in some places contains freshwater and land species, and never any marine fossils. The calcaire siliceux and the calcaire grossier usually occupy distinct parts of the Paris Basin, the one attaining its fullest development in those places where the other is of slight thickness. They are described by some writers as alternating with each other towards the centre of the basin, as at Sergy and Osny.

The gypsum, with its associated marls before described, is in greatest force towards the centre of the basin, where the calcaire grossier and calcaire siliceux are less fully developed.

Grès de Beauchamp, or Sables Moyens (A. 4, Table, p. 234). —In some parts of the Paris Basin, sands and marls, called the Grès de Beauchamp, or Sables moyens, divide the gypseous beds from the calcaire grossier proper. These sands, in which a small nummulite (*N. variolaria*) is very abundant, contain more than 300 species of marine shells, many of them peculiar, but others common to the next division.

MIDDLE EOCENE FORMATIONS OF FRANCE.

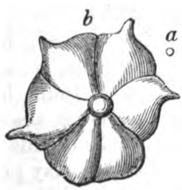
Calcaire Grossier, upper and middle (B. 1, Table, p. 234). —The upper division of this group consists in great part of beds of compact, fragile limestone, with some intercalated green marls. The shells in some parts are a mixture of *Cerithium*, *Cyclostoma*, and *Corbula*; in others *Limnæa*, *Cerithium*, *Paludina*, &c. In the latter, the bones of reptiles and mammalia, *Palæotherium* and *Lophiodon*, have been found. The middle division, or calcaire grossier proper, consists of a coarse limestone, often passing into sand. It contains the greater number of the fossil shells which characterise the Paris Basin. No less than 400 distinct

species have been procured from a single spot near Grignon, where they are embedded in a calcareous sand, chiefly formed of comminuted shells, in which, nevertheless, individuals in a perfect state of preservation, both of marine, terrestrial, and freshwater species, are mingled together. Some of the marine shells may have lived on the spot; but the *Cyclostoma* and *Limnæa*, being land and freshwater shells, must have been brought thither by rivers and currents, and the quantity of triturated shells implies considerable movement in the waters.

Nothing is more striking in this assemblage of fossil testacea than the great proportion of species referable to the genus *Cerithium* (see figures, p. 227). There occur no less than 137 species of this genus in the Paris Basin, and almost all of them in the calcaire grossier. Most of the living *Cerithia* inhabit the sea near the mouths of rivers, where the waters are brackish; so that their abundance in the marine strata now under consideration is in harmony with the hypothesis that the Paris Basin formed a gulf into which several rivers flowed.

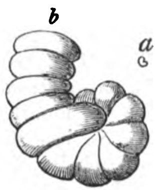
EOCENE FORAMINIFERA.

Fig. 221.



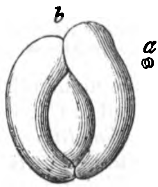
Calcarina rarispina, Desh.

Fig. 222.



Spirolina stenostoma, Desh.

Fig. 223.



Triloculina inflata, Desh.

a. Natural size. *b*. Magnified.

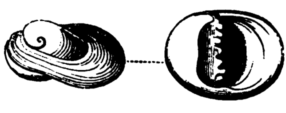
In some parts of the calcaire grossier round Paris, certain beds occur of a stone used in building, and called by the French geologists 'Miliolite limestone.' It is almost entirely made up of millions of microscopic shells, of the size of minute grains of sand, which all belong to the class Foraminifera. Figures of some of these are given in the annexed woodcut. As this miliolitic stone never occurs in the Faluns, or Upper Miocene strata of Brittany and Touraine, it often furnishes the geologist with a useful criterion for distinguishing the detached Eocene and Upper Miocene formations scattered over those and other adjoining provinces. The discovery of the remains of Palæotherium and other mammalia in some of the upper beds of the cal-

caire grossier shows that these land animals began to exist before the deposition of the overlying gypseous series had commenced.

Lower Calcaire grossier, or Glauconie grossière (B. 1, Table, p. 234).—The lower part of the calcaire grossier, which often contains much green earth, is characterised at Auvers, near Pontoise, to the north of Paris, and still more in the environs of Compiègne, by the abundance of nummulites, consisting chiefly of *N. lævigata*, *N. scabra*, and *N. Lamarcki*, which constitute a large proportion of some of the stony strata, though these same foraminifera are wanting in beds of similar age in the immediate environs of Paris.

Soissonnais sands, or Lits coquilliers (B. 2, Table, p. 234).—Below the preceding formation shelly sands are seen, of considerable thickness, especially at Cuisse-Lamotte, near Compiègne, and other localities in the Soissonnais, about fifty miles N.E. of Paris, from which about 300 species of shells have been obtained, many of them common to the calcaire grossier and the Bracklesham beds of England, and many peculiar. The *Nummulites planulata* is very abundant, and the most characteristic shell is the *Nerita conoidea*, Lam., a fossil which has a very wide geographical range; for, as M. d'Archiac remarks, it accompanies the nummulitic formation from Europe to India, having been found in Cutch, near the mouths of the Indus, associated with *Nummulites scabra.* No less than 33 shells of this group are said to be identical with shells of the London clay proper; yet, after visiting Cuisse-Lamotte and other localities of the 'Sables inférieurs' of D'Archiac, I agree with Mr. Prestwich that the latter are probably newer than the London clay, and perhaps older than the Bracklesham beds of England. The London clay seems to be unrepresented in the Paris Basin, unless partially so, by these sands.[1]

Fig. 224.



Nerita conoidea, Lam. ½.
Syn. N *Schmidelliana*, Chemnitz.

LOWER EOCENE FORMATIONS OF FRANCE.

Argile plastique (C. 2, Table, p. 234).—At the base of the Tertiary system in France are extensive deposits of sands, with occasional beds of clay used for pottery, and called 'argile plastique.' Fossil oysters (*Ostrea bellovacina*) abound in some places; and in others there is a mixture of fluviatile shells, such as

[1] D'Archiac, Bulletin, tom. x.; and Prestwich, Geol. Quart. Journ. 1847, p. 377.

Cyrena cuneiformis (fig. 215, p. 250), *Melania inquinata* (fig. 216), and others, frequently met with in beds occupying the same position in the London Basin. Layers of lignite also accompany the inferior clays and sands.

Immediately upon the chalk at the bottom of all the tertiary strata in France there generally is a conglomerate or breccia of rolled and angular chalk-flints, cemented by siliceous sand. These beds appear to be of littoral origin, and imply the previous emergence of the chalk, and its waste by denudation. In the year 1855, the tibia and femur of a large bird, equalling at least the ostrich in size, were found at Meudon, near Paris, at the base of the Plastic clay. This bird, to which the name of *Gastornis Parisiensis* has been assigned, appears, from the Memoirs of MM. Hébert, Lartet, and Owen, to belong to an extinct genus. Professor Owen refers it to the class of wading land birds rather than to an aquatic species.[2]

That a formation so much explored for economical purposes as the Argile plastique around Paris, and the clays and sands of corresponding age near London, should never have afforded any vestige of a feathered biped previously to the year 1855, shows what diligent search and what skill in osteological interpretation are required before the existence of birds of remote ages can be established.

Sables de Bracheux (C. 3, Table, p. 234).—The marine sands called the Sables de Bracheux (a place near Beauvais) are considered by M. Hébert to be older than the Lignites and Plastic clay, and to coincide in age with the Thanet Sands of England. At La Fère, in the Department of Aisne, in a deposit of this age, a fossil skull has been found of a quadruped called by Blainville *Arctocyon primævus*, and supposed by him to be related both to the bear and to the Kinkajou (*Cercoleptes*). This creature appears to be the oldest known tertiary mammifer.

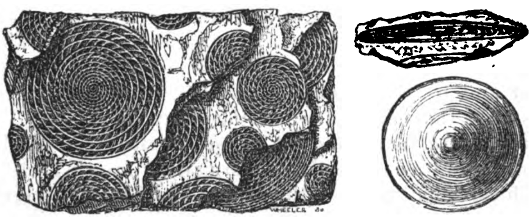
Nummulitic formation of Europe, Asia, &c.—Of all the rocks of the Eocene period, no formations are of such great geographical importance as the Upper and Middle Eocene, as above defined, assuming that the older tertiary formation, commonly called nummulitic, is correctly ascribed to this group. It appears that of more than fifty species of these foraminifera described by D'Archiac, one or two species only are found in other tertiary formations whether of older or newer date. *Nummulites intermedia*, a Middle Eocene form, ascends into the Lower Miocene, but it seems doubtful whether any species descends to the level of the London clay, still less to the

[2] Quart. Geol. Journ., vol. xii. p. 204. 1856.

Argile plastique or Woolwich beds. Separate groups of strata are often characterised by distinct species of nummulite; thus the beds between the Lower Miocene and the Lower Eocene may be divided into three sections, distinguished by three different species of nummulites—*N. variolaria* in the upper, *N. lævigata* in the middle, and *N. planulata* in the lower beds. The nummulitic limestone of the Swiss Alps rises to more than 10,000 feet above the level of the sea, and attains here and in other mountain-chains a thickness of several thousand feet. It may be said to play a far more conspicuous part than any other tertiary group in the solid framework of the earth's crust, whether in Europe, Asia, or Africa. It occurs in Algeria and Morocco, and has been traced from Egypt, where it was largely quarried of old for the building of the Pyramids, into Asia Minor, and across Persia by Bagdad to the mouths of the Indus. It has been observed not only in Cutch, but in the mountain-ranges which separate Scinde from Persia, and which form the passes leading to Cabul; and it has been followed still farther eastward into India, as far as Eastern Bengal and the frontiers of China.

Dr. T. Thomson found nummulites in Western Thibet at an elevation of no less than 16,500 feet above the level of the sea. One of the species, which I myself found very abundant on the flanks of the Pyrenees, in a compact crystalline marble (fig. 225), is called by M. d'Archiac *Nummulites Puschi*. The same is also

Fig. 225.



Nummulites Puschi, D'Archiac, $\frac{2}{3}$. Peyrehorade, Pyrenees.
a. External surface of one of the nummulites, of which longitudinal sections are seen in the limestone. *b.* Transverse section of same.

very common in rocks of the same age in the Carpathians. In many distant countries, in Cutch, for example, some of the same shells, such as *Nerita conoidea* (fig. 224), accompany the nummulites, as in France. The opinion of many observers, that the Nummulitic formation belongs partly to the cretaceous era, seems chiefly to have arisen from confounding an allied genus, Orbitoides, with the true Nummulite.

When we have once arrived at the conviction that the nummulitic formation occupies a middle and upper place in the Eocene series, we are struck with the comparatively modern date to which some of the greatest revolutions in the physical geography of Europe, Asia, and Northern Africa must be referred. All the mountain-chains, such as the Alps, Pyrenees, Carpathians, and Himalayas, into the composition of whose central and loftiest parts the nummulitic strata enter bodily, could have had no existence till after the Middle Eocene period. During that period the sea prevailed where these chains now rise, for nummulites and their accompanying testacea were unquestionably inhabitants of salt water. Before these events, comprising the conversion of a wide area from a sea to a continent, England had been peopled, as I before pointed out (p. 247), by various quadrupeds, by herbivorous pachyderms, by insectivorous bats, and by opossums.

Almost all the volcanoes which preserve any remains of their original form, or from the craters of which lava streams can be traced, are more modern than the Eocene fauna now under consideration; and besides these superficial monuments of the action of heat, Plutonic influences have worked vast changes in the texture of rocks within the same period. Some members of the nummulitic and overlying tertiary strata called *flysch* have actually been converted in the central Alps into crystalline rocks, and transformed into marble, quartz-rock, mica-schist, and gneiss.[3]

Eocene strata in the United States.—In North America the Eocene formations occupy a large area bordering the Atlantic, which increases in breadth and importance as it is traced southwards from Delaware and Maryland to Georgia and Alabama. They also occur in Louisiana and other states both east and west of the valley of the Mississippi. At Claiborne, in Alabama, no less than 400 species of marine shells, with many echinoderms and teeth of fish, characterise one member of this system. Among the shells, the *Cardita planicosta*, before mentioned (fig. 190, p. 242), is in abundance; and this fossil and some others identical with European species, or very nearly allied to them, make it highly probable that the Claiborne beds agree in age with the central or Bracklesham group of England, and with the Calcaire grossier of Paris.[4]

Higher in the series is a remarkable calcareous rock, formerly

[3] Murchison, Quart. Journ. of Geol. Soc., vol. v., and Lyell, vol. vi. 1850. Anniversary Address.

[4] See paper by the Author, Quart. Journ. Geol. Soc., vol. iv. p. 12; and Second Visit to the United States, vol. ii. p. 59.

called 'the nummulite limestone,' from the great number of discoid bodies resembling nummulites which it contains—fossils now referred by A. D'Orbigny to the genus *Orbitoides*, which has been demonstrated by Dr. Carpenter to belong to the foraminifera.[5] That naturalist, moreover, is of opinion that the Orbitoides alluded to (*O. Mantelli*) is of the same species as one found in Cutch in the Middle Eocene or nummulitic formation of India.

Above the orbitoidal limestone is a white limestone, sometimes soft and argillaceous, but in parts very compact and calcareous. It contains several peculiar corals, and a large Nautilus allied to *N. ziczac*; also in its upper bed a gigantic cetacean, called *Zeuglodon* by Owen.[6]

The colossal bones of this cetacean are so plentiful in the interior of Clarke County, Alabama, as to be characteristic of the formation. The vertebral column of one skeleton found by Dr.

Fig. 226.

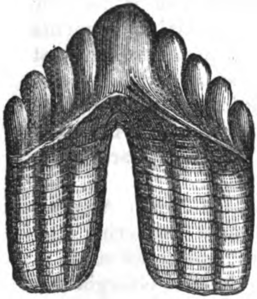
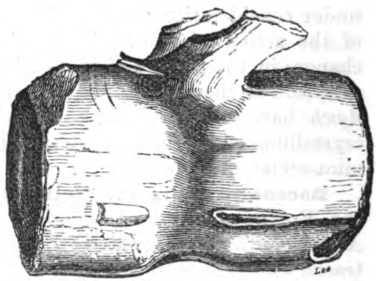


Fig. 227.



Zeuglodon cetoides, Owen.
Basilosaurus, Harlan.

Molar tooth, natural size. Vertebra, reduced.

Buckley at a spot visited by me, extended to the length of nearly seventy feet, and not far off part of another backbone nearly fifty feet long was dug up. I obtained evidence, during a short excursion, of so many localities of this fossil animal within a distance of ten miles, as to lead me to conclude that they must have belonged to at least forty distinct individuals.

Prof. Owen first pointed out that this huge animal was not reptilian, since each tooth was furnished with double roots (fig. 226), implanted in corresponding double sockets; and his

[5] Quart. Journ. Geol. Soc., vol. vi. p. 32.

[6] See Memoir by R. W. Gibbes, Journ. of Acad. Nat. Sci. Philad., vol. i. 1847.

opinion of the cetacean nature of the fossil was afterwards confirmed by Dr. Wyman and Dr. R. W. Gibbes. That it was an extinct mammal of the whale tribe has since been placed beyond all doubt by the discovery of the entire skull of another fossil species of the same family, having the double occipital condyles only met with in mammals, and the convoluted tympanic bones which are characteristic of cetaceans.

SECONDARY OR MESOZOIC SERIES.

CHAPTER XVII.

UPPER CRETACEOUS GROUP.

Lapse of time between Cretaceous and Eocene periods—Table of successive Cretaceous formations—Maestricht beds—Pisolitic limestone of France—Chalk of Faxoe—Geographical extent and origin of the White Chalk—Chalky matter now forming in the bed of the Atlantic—Marked difference between the Cretaceous and existing fauna—Chalk flints—Potstones of Horstead—Vitreous sponges in the Chalk—Isolated blocks of foreign rocks in the white chalk, supposed to be iceborne—Distinctness of mineral character in contemporaneous rocks of the Cretaceous epoch—Fossils of the white chalk—Lower white chalk without flints—Chalk Marl and its fossils—Chloritic series or Upper Greensand—Coprolite bed near Cambridge—Fossils of the Chloritic series—Gault—Connection between Upper and Lower Cretaceous strata—Blackdown beds—Flora of the Upper Cretaceous period—Hippurite Limestone—Cretaceous rocks in the United States.

We have treated in the preceding chapters of the Tertiary or Cainozoic strata, and have next to speak of the Secondary or Mesozoic formations. The uppermost of these last is commonly called the chalk or the cretaceous formation, from *creta*, the Latin name for that remarkable white, earthy limestone which constitutes an upper member of the group in those parts of Europe where it was first studied. The marked discordance in the fossils of the tertiary, as compared with the cretaceous formations, has long induced many geologists to suspect that an indefinite series of ages elapsed between the respective periods of their origin. Measured, indeed, by such a standard—that is to say, by the amount of change in the Fauna and Flora of the earth effected in the interval—the time between the Cretaceous and Eocene may have been as great as that between the Eocene and Recent periods, to the history of which the last seven chapters have been devoted. Several deposits have been met with here and there, in the course of the last half century, of an age intermediate between the white chalk and the plastic clays and sands of the Paris and London districts—monuments which have the same kind of interest to a geologist which certain mediæval records

excite when we study the history of nations. For both of them throw light on ages of darkness, preceded and followed by others of which the annals are comparatively well known to us. But these newly-discovered records do not fill up the wide gap, some of them being closely allied to the Eocene, and others to the Cretaceous type, while none appear as yet to possess so distinct and characteristic a fauna as may entitle them to hold an independent place in the great chronological series.

Among the formations alluded to, the Thanet Sands of Prestwich have been sufficiently described in the last chapter, and classed as Lower Eocene. To the same tertiary series belong the Belgian formations, called by Professor Dumont, Landenian. On the other hand, the Maestricht and Faxoe limestones are very closely connected with the chalk, to which also the Pisolitic limestone of France is referable.

Classification of the Cretaceous rocks.—The Cretaceous group has generally been divided into an Upper and a Lower series, the Upper called familiarly *the chalk*, and the Lower *the greensand*; the one deriving its name from the predominance of white earthy limestone and marl, of which it consists in a great part of France and England, the other or Lower series from the plentiful mixture of green or chloritic grains contained in some of the sands and cherts of which it largely consists in the same countries. But these mineral characters often fail, even when we attempt to follow out the same continuous subdivisions throughout a small portion of the North of Europe, and are worse than valueless when we desire to apply them to more distant regions. It is only by aid of the organic remains which characterise the successive marine subdivisions of the formation that we are able to recognise in remote countries, such as the South of Europe or North America, the formations which were there contemporaneously in progress. To the English student of geology it will be sufficient to begin by enumerating those groups which characterise the series in this country and others immediately contiguous, alluding but slightly to those of more distant regions. In the annexed table it will be seen that I have used the term Neocomian for that commonly called 'Lower Greensand;' this latter term being peculiarly objectionable because the green grains are an exception to the rule in many of the members of this group even in districts where it was first studied and named. M. Alcide D'Orbigny, in his valuable work entitled 'Paléontologie Française,' has adopted new terms for the French subdivisions of the Upper Cretaceous series, and these are now so generally used by foreign writers that the student should endeavour to remember their relation to the

English equivalents so far as it is possible to make them agree.

UPPER CRETACEOUS OR CHALK PERIOD.

English subdivisions.	French equivalents.
1. Maestricht Beds, Faxoe Limestone, and Pisolitic Limestone of France.	1. Étage Danien.
2. Upper White Chalk, with flints.	2. Sénonien in part.
3. Lower White Chalk, without flints.	3. Sénonien in part.
4. Chalk Marl.	4. Sénonien in part and Turonien.
5. Chloritic series (or Upper Greensand).	5. Cénomanien.
6. Gault.	6. Albien.

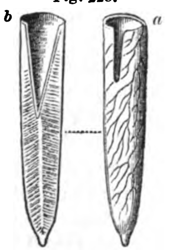
LOWER CRETACEOUS OR NEOCOMIAN.

(Néocomien of the French.)[1]

Marine.	Freshwater.
1. Upper Neocomian, see p. 292.	Wealden Beds (upper part).
2. Middle Neocomian, see p. 296.	
3. Lower Neocomian, see p. 297.	

Maestricht Beds.—On the banks of the Meuse, at Maestricht, reposing on ordinary white chalk with flints, we find an upper calcareous formation about 100 feet thick, the fossils of which are, on the whole, very peculiar, and all distinct from Tertiary species. Some few are of species common to the inferior white chalk, among which may be mentioned *Belemnitella mucronata* (fig. 228) and *Pecten quadricostatus*, a shell regarded by many as a mere variety of *P. quinquecostatus* (see fig. 272, p. 284). Besides the Belemnite there are other *genera*, such as *Baculites* and *Hamites*, never found in strata newer than the cretaceous, but frequently met with in these Maestricht beds. On the other hand, *Voluta*, *Fasciolaria*, and other genera of univalve shells occur, which are usually met with only in tertiary strata.

Fig. 228.



Belemnitella mucronata, ½. Maestricht, Faxoe, and White Chalk.

a. Osselet or guard, showing vascular impressions on outer surface, with characteristic slit, and mucro.
b. Section of same, showing place of phragmocone.[2]

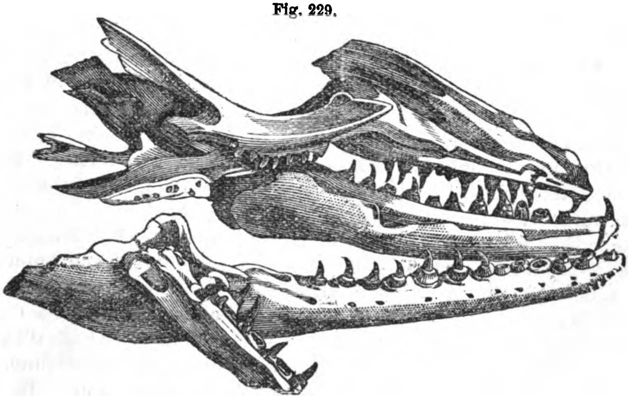
[1] The Lower Cretaceous or Neocomian is also called Néocomien by the French; the name Aptien, formerly adopted by D'Orbigny for the Upper Neocomian, being now but rarely used.

[2] For particulars of structure, see p. 327.

The upper part of the rock, about 20 feet thick, as seen in St. Peter's Mount, in the suburbs of Maestricht, abounds in corals and Polyzoa, often separable from the matrix; and these beds are succeeded by a soft yellowish limestone 50 feet thick, extensively quarried from time immemorial for building. The stone below is whiter, and contains occasional nodules of grey chert or chalcedony.

M. Bosquet, with whom I examined this formation (August, 1850), pointed out to me a layer of chalk from two to four inches thick, containing green earth and numerous encrinital stems, which forms the line of demarcation between the strata

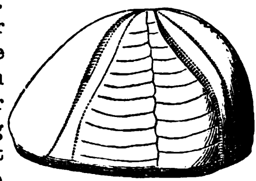
Fig. 229.



Mosasaurus Camperi. Original more than three feet long.

containing the fossils peculiar to Maestricht and the white chalk below. The latter is distinguished by regular layers of black flint in nodules, and by shells, such as *Terebratula carnea* (see fig. 248, p. 277), wholly wanting in beds higher than the green band. Some of the organic remains, however, for which St. Peter's Mount is celebrated, occur both above and below that parting layer, and, among others, the great marine reptile called *Mosasaurus* (see fig. 229), a saurian supposed to have been 24 feet in length, of which the entire skull and a great part of the skeleton have been found. Such remains are chiefly met with in the soft freestone, the principal member of the Maestricht

Fig. 230.



Hemipneustes radiatus, Ag.
Spatangus radiatus, Lam.
Chalk of Maestricht and white chalk.

beds. Among the fossils common to the Maestricht and white chalk may be instanced the echinoderm (fig. 230).

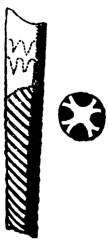
I saw proofs of the previous denudation of the white chalk exhibited in the lower bed of the Maestricht formation in Belgium, about 30 miles S.W. of Maestricht, at the village of Jendrain, where the base of the newer deposit consisted chiefly of a layer of well-rolled, black, chalk-flint pebbles, in the midst of which perfect specimens of *Thecidea pappillata* and *Belemnitella mucronata* are embedded. To a geologist accustomed in England to regard rolled pebbles of chalk-flint as a common and distinctive feature of tertiary beds of different ages, it is a new and surprising phenomenon to behold strata made up of such materials and yet to feel no doubt that they were accumulated in a sea in which the belemnite and other cretaceous mollusca flourished.

Pisolitic limestone of France.—Geologists were for many years at variance respecting the chronological relations of this rock, which is met with in the neighbourhood of Paris, and at places north, south, east and west of that metropolis, as between Vertus and Laversines, Meudon and Montereau. By many able palæontologists the species of fossils, more than 50 in number, were declared to be more Eocene in their appearance than Cretaceous. But M. Hébert found in this formation at Montereau, near Paris, the *Pecten quadricostatus*, a well-known Cretaceous species, together with some other fossils common to the Maestricht chalk and to the Baculite limestone of the Cotentin in Normandy. He therefore, as well as M. Alcide d'Orbigny, who had carefully studied the fossils, came to the opinion that it was an upper member of the Cretaceous group. It is usually in the form of a coarse yellowish or whitish limestone, and the total thickness of the series of beds already known is about 100 feet. Its geographical range, according to M. Hébert, is not less than 45 leagues from east to west, and 35 from north to south. Within these limits it occurs in small patches only, resting unconformably on the white chalk.

The *Nautilus Danicus* (fig. 232), and two or three other species found in this rock, are frequent in that of Faxoe in Denmark, but as yet no Ammonites, Hamites, Scaphites, Turrilites, Baculites, or Hippurites have been met with. The proportion of peculiar species, many of them of tertiary aspect, is confessedly large; and great aqueous erosion suffered by the white chalk, before the pisolitic limestone was formed, affords an additional indication of the two deposits being widely separated in time. The pisolitic formation, therefore, may eventually prove to be somewhat more intermediate in date between the secondary and tertiary epochs than the Maestricht rock.

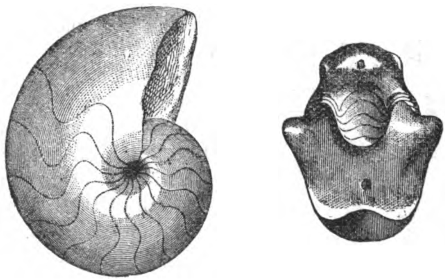
Chalk of Faxoe.—In the island of Seeland, in Denmark, the newest member of the chalk series, seen in the sea-cliffs at Stevensklint resting on white chalk with flints, is a yellow limestone, a portion of which, at Faxoe, where it is used as a building-stone, is composed of corals, even more conspicuously than is usually observed in recent coral reefs. It has been quarried to the depth of more than 40 feet, but its thickness is unknown. The embedded shells are chiefly casts, many of them of univalve mollusca, which are usually very rare in the white chalk of Europe. Thus there are two species of *Cypræa*, one of *Oliva*, two of *Mitra*, four of the genus *Cerithium*, six of *Fusus*, two of *Trochus*, one of *Patella*, one of *Emarginula*, &c. ; on the whole, more than thirty univalves, spiral or patelliform. At the same time, some of the accompanying bivalve shells, echinoderms, and zoophytes are specifically identical with fossils of the true Cretaceous series. Among the cephalopoda of Faxoe may be

Fig. 231.



Portion of *Baculites Faujasii*, Sow. Maestricht and Faxoe beds and white chalk.

Fig. 232.



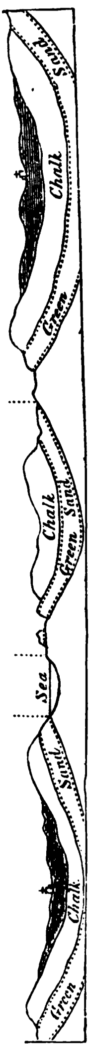
Nautilus Danicus, Schl. Faxoe, Denmark.

mentioned *Baculites Faujasii* (fig. 231), and *Belemnitella mucronata* (fig. 228, p. 266), shells of the white chalk. The *Nautilus Danicus* (see fig. 232) is characteristic of this formation ; and it also occurs in France in the calcaire pisolitique of Laversin (Department of Oise). The claws and entire carapace of a small crab, *Brachyurus rugosus* (Schlott.), are scattered through the Faxoe stone, reminding us of similar crustaceans enclosed in the rocks of modern coral reefs. Some small portions of this coral formation consist of white earthy chalk.

Composition, extent, and origin of the White Chalk.—The highest beds of chalk in England and France consist of a pure, white calcareous mass, usually too soft for a building-stone, but sometimes passing into a more solid state. It consists, almost purely, of carbonate of lime ; the stratification is often obscure, except where rendered distinct by interstratified layers of flint,

a few inches thick, occasionally in continuous beds, but oftener in nodules, and recurring at intervals generally from two to four feet distant from each other. This upper chalk is usually succeeded, in the descending order, by a great mass of white chalk, without flints, below which comes the chalk marl, in which there is a slight admixture of argillaceous matter. The united thickness of the three divisions in the South of England equals, in some places, 1,000 feet. The annexed section (fig. 233) will show the manner in which the white chalk extends from England into France, covered by the tertiary strata described in former chapters, and reposing on lower cretaceous beds.

Fig. 233.



Diagrammatic section from Hertfordshire, in England, to Sens, in France.

The area over which the white chalk preserves a nearly homogeneous aspect is so vast, that the earlier geologists despaired of discovering any analogous deposits of recent date. Pure chalk, of nearly uniform aspect and composition, is met with in a north-west and south-east direction, from the North of Ireland to the Crimea, a distance of about 1,140 geographical miles; and in an opposite direction it extends from the south of Sweden to the south of Bordeaux, a distance of about 840 geographical miles. In Southern Russia, according to Sir R. Murchison, it is sometimes 600 feet thick, and retains the same mineral character as in France and England with the same fossils, including *Inoceramus Cuvieri*, *Belemnitella mucronata*, and *Ostrea vesicularis* (fig. 253, p. 278).

Much light has recently been thrown upon the origin of the unconsolidated white chalk by the deep soundings made in the North Atlantic, previous to laying down, in 1858, the electric telegraph between Ireland and Newfoundland. At depths sometimes exceeding two miles, the mud forming the floor of the ocean was found, by Professor Huxley, to be almost entirely composed (more than nineteen-twentieths of the whole) of minute Rhizopods or foraminiferal shells of the genus *Globigerina*, especially the species *Globigerina bulloides* (see fig. 234). The

organic bodies next in quantity were the siliceous shells called *Polycystineæ*, and next to them the siliceous skeletons of plants called *Diatomaceæ* (figs. 235, 236, 237), and occasionally some siliceous spiculæ of sponges (fig. 238) were intermixed.

Fig. 234.

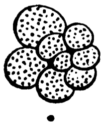


Fig. 235.

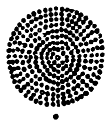


Fig. 236.

Fig. 237.

Fig. 238.

Organic bodies forming the bed of the ooze of the Atlantic at great depths.

Fig. 234. *Globigerina bulloides.* *Calcareous Rhizoped.*
235. *Actinocyclus.*
236. *Pinnularia.* } *Siliceous Diatomaceæ.*
237. *Eunotia bidens.*
238. *Spicula* of sponge. *Siliceous sponge.*

It also contains abundance of very minute bodies termed Coccoliths and Coccospheres, which have also been detected fossil in chalk, though their true nature is not yet made out.

Sir Leopold M'Clintock and Dr. Wallich have ascertained that 95 per cent. of the mud of a large part of the North Atlantic consists of the shells of Globigerina. But Capt. Bullock, R.N., lately brought up from the enormous depth of 16,860 feet a white, viscid, chalky mud, wholly devoid of Globigerinæ. This mud was perfectly homogeneous in composition, and contained no organic remains visible to the naked eye. Mr. Etheridge, however, has ascertained by microscopical examination that it is made up of *Coccoliths*, *Discoliths*, and other minute fossils like those of the Chalk. This white mud, more than three miles deep, was dredged up in lat. 20° 19′ N., long. 4° 36′ E., or about midway between Madeira and the Cape of Good Hope.

The recent deep-sea dredgings in the Atlantic conducted by Sir C. Wyville Thomson,[3] Dr. Carpenter, Mr. Gwyn Jeffreys, and others, have shown that on the same white mud there sometimes flourish Mollusca, Crustacea, and Echinoderms, besides abundance of siliceous sponges, forming on the whole a marine fauna bearing a striking resemblance in its general character to that of the ancient chalk.

Popular error as to the geological continuity of the Cretaceous period.—We must be careful, however, not to overrate

[3] An interesting account of the results of the dredging cruises will be found in Sir C. W. Thomson's admirable work 'The Depths of the Sea.' 1873.

the points of resemblance which the deep-sea investigations have placed in a strong light. They have been supposed by some naturalists to warrant a conclusion expressed in these words: 'we are still living in the Cretaceous epoch;' a doctrine which has led to much popular delusion as to the bearing of the new facts on geological reasoning and classification. The reader should be reminded that in geology we have been in the habit of founding our great chronological divisions, not in foraminifera and sponges, nor even on echinoderms and corals, but on the remains of the most highly organised beings available to us, such as the mollusca; these being met with, as above explained (p. 121), in stratified rocks of almost every age. In dealing with the mollusca, it is those of the highest or most specialised organisation which afford us the best characters in proportion as their vertical range is the most limited. Thus the Cephalopoda are the most valuable as having a more restricted range in time than the Gasteropoda, and these again are more characteristic of the particular stratigraphical subdivisions than are the Lamellibranchiate Bivalves, while these last again are more serviceable in classification than the Brachiopoda, a still lower class of shell-fish, which are the most enduring of all.

When told that the new dredgings prove that 'we are still living in the Chalk Period,' we naturally ask whether some cuttle-fish has been found with a belemnite forming part of its internal framework; or have Ammonites, Baculites, Hamites, Turrilites, with four or five other Cephalopodous genera characteristic of the chalk and unknown as tertiary, been met with in the abysses of the ocean? Or, in the absence of these long-extinct forms, has a single spiral univalve, or species of Cretaceous Gasteropod, been found living? Or, to descend still lower in the scale, has some characteristic Cretaceous genus of Lamellibranchiata, such as the Inoceramus, or Hippurite, foreign to the Tertiary seas, been proved to have survived down to our time? Or of the numerous genera of Lamellibranchiata common to the Cretaceous and Recent seas, has one species been found living? The answer to all these questions is—not one has been found. Even amongst the lowly-organised Brachiopods, no species common to the Cretaceous and Recent seas has yet been met with. It has been very generally admitted by conchologists that out of a hundred species of this tribe occurring fossil in the Upper Chalk—one and one only, *Terebratulina striata*, is still living, being thought to be identical with *Terebratula caput-serpentis*. Although this identity is still questioned by some naturalists of authority, it would certainly not

surprise us if other 'lamp-shells' of equal antiquity should be met with in the deep sea.

Had it been declared that we are living in the Eocene epoch, the idea would not be so extravagant, for the great reptiles of the Upper Chalk, the Mosasaurus, Pliosaurus, and Pterodactyle, and many others, as well as so many genera of chambered univalves, had already disappeared from the earth, and the marine fauna had made a greater approach to our own by nearly the entire difference which separates it from the fauna of the Cretaceous seas. The Eocene nummulitic limestone of Egypt is a rock mainly composed, like the more ancient white chalk, of globigerine and textularian mud; and when we consider the extent to which the nummulitic marine strata, formed originally at the bottom of the sea, now form part of the framework of mountain chains of the principal continents, it will be at once perceived that the present Atlantic, Pacific, and Indian Oceans are geographical terms, which lose their meaning when applied to the Eocene, and still more antecedent to the Cretaceous period.

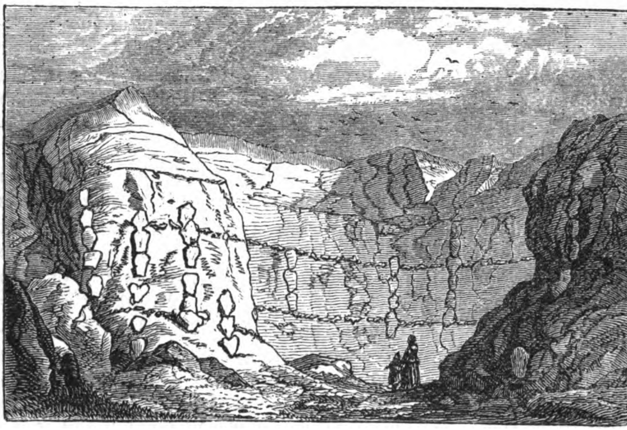
Chalk flints.—The origin of the layers of flint, whether in the form of nodules, or continuous sheets, or in veins or cracks not parallel to the stratification, has always been more difficult to explain than that of the white chalk. But here again the late deep-sea soundings have suggested a possible source of such mineral matter. During the cruise of the 'Bulldog,' already alluded to, it was ascertained that while the calcareous *Globigerinæ* had almost exclusive possession of certain tracts of the sea-bottom, they were wholly wanting in others, as between Greenland and Labrador. According to Dr. Wallich, they may flourish in those spaces where they derive nutriment from organic and other matter, brought from the south by the warm waters of the Gulf Stream, and they may be absent where the effects of that great current are not felt. Now in several of the spaces where the calcareous Rhizopods are wanting, certain microscopic plants, called *Diatomaceæ*, above mentioned (figs. 235-237), the solid parts of which are siliceous, monopolise the area at a depth of nearly 400 fathoms, or 2,400 feet.

The large quantities of silex in solution required for the formation of these plants may probably arise from the disintegration of felspathic rocks, which are universally distributed. As more than half of their bulk is formed of siliceous earth, they may afford an endless supply of silica to all the great rivers which flow into the ocean. We may imagine that after a lapse of many years or centuries, changes took place in the direction of the marine currents, favouring at one time a supply in the same

area of siliceous, and at another of calcareous matter in excess, giving rise in the one case to a preponderance of Diatomaceæ, and in the other of Globigerinæ. These last, together with certain sponges, may by their decomposition have furnished the silex, which, separating from the chalky mud, collected round organic bodies, or formed nodules or filled shrinkage cracks.

Potstones. Vitreous sponges of the Chalk.—A more difficult enigma is presented by the occurrence of certain huge flints, or potstones, as they are called in Norfolk, occurring singly, or arranged in nearly continuous columns at right angles to the ordinary and horizontal layers of small flints. I visited

Fig. 239.



From a drawing by Mrs. Gunn.

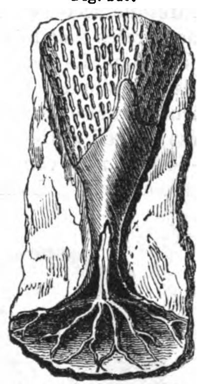
View of a chalk-pit at Horstead, near Norwich, showing the position of the potstones.

in the year 1825 an extensive range of quarries then open on the river Bure, near Horstead, about six miles from Norwich, which afforded a continuous section, a quarter of a mile in length, of white chalk, exposed to the depth of about twenty-six feet, and covered by a bed of gravel. The potstones, many of them pear-shaped, were usually about three feet in height and one foot in their transverse diameter, placed in vertical rows, like pillars, at irregular distances from each other, but usually from twenty to thirty feet apart, though sometimes nearer together, as in the above sketch. These rows did not terminate downwards in any instance which I could examine, nor upwards, except at the point where they were cut off

abruptly by the bed of gravel. On breaking open the potstones, I found an internal cylindrical nucleus of pure chalk, much harder than the ordinary surrounding chalk, and not crumbling to pieces, like it, when exposed to the winter's frost. At the distance of half a mile, the vertical piles of potstones were much farther apart from each other. Dr. Buckland has described very similar phenomena as characterising the white chalk on the north coast of Antrim in Ireland.[4] These pear-shaped masses of flint often resemble in shape and size the large sponges called Neptune's Cups (*Spongia patera*, Hardw.), which grow in the seas of Sumatra; and if we could suppose a series of such gigantic sponges to be separated from each other, like trees in a forest, and the individuals of each successive generation to grow on the exact spot where the parent sponge died and was enveloped in calcareous mud, so that they should become piled one above the other in a vertical column, their growth keeping pace with the accumulation of the enveloping calcareous mud, a counterpart of the phenomena of the Horstead potstones might be obtained.

Professor Wyville Thomson, describing the modern soundings in 1869 off the north coast of Scotland, speaks of the ooze or chalk mud brought from a depth of about 3,000 feet, and states that at one haul they obtained forty specimens of vitreous sponges buried in the mud. He suggests that the Ventriculites of the chalk were nearly allied to these sponges, and that when the silica of their spicules was removed, and was dissolved out of the calcareous matrix, it set into flint.[5]

Fig. 240.



Ventriculites radiatus. Mantell. Syn. *Ocellaria radiata.* D'Orb. ½. White chalk.

Boulders and groups of pebbles in chalk.—The occurrence here and there in the white chalk of the South of England of isolated pebbles of quartz and green schist has justly excited much wonder. It was at first supposed that they had been dropped from the roots of some floating tree, by which means stones are carried to some of the small coral islands of the Pacific. But the discovery in 1857 of a group of stones in the white chalk near Croydon,

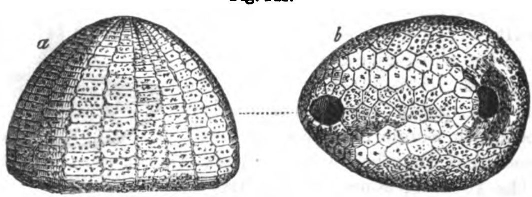
[4] Geol. Trans., 1st Series, vol. iv. p. 413.

[5] See also Depths of the Sea, 1873, p. 482.

the largest of which was syenite and weighed about forty pounds, accompanied by pebbles and fine sand like that of a beach, has been shown by Mr. Godwin Austen to be inexplicable except by the agency of floating ice. If we consider that icebergs now reach 40° north latitude in the Atlantic, and several degrees nearer the equator in the southern hemisphere, we can the more easily believe that even during the Cretaceous epoch, assuming that the climate was milder, fragments of coast ice may have floated occasionally as far as the South of England.

Distinctness of mineral character in contemporaneous rocks of the Cretaceous period.—But we must not imagine that because pebbles are so rare in the white chalk of England and France there are no proofs of sand, shingle, and clay having been accumulated contemporaneously even in European seas. The siliceous sandstone, called 'upper quader' by the Germans, overlies white argillaceous chalk, or 'pläner-kalk,' a deposit resembling in composition and organic remains the chalk marl of the English series. This sandstone contains as many fossil shells common to our white chalk as could be expected in a sea-bottom formed of such different materials. It sometimes attains a thickness of 600 feet, and, by its jointed structure and vertical precipices, plays a conspicuous part in the picturesque scenery of Saxon Switzerland, near Dresden. It demonstrates that in the Cretaceous sea, as in our own, distinct mineral deposits were simultaneously in progress. The quartzose sandstone alluded to, derived from the detritus of the neighbouring granite, is absolutely devoid of carbonate of lime, yet it was formed at the distance only of four hundred miles from a sea-bottom now constituting part of France, where the purely calcareous white chalk was forming. In the North American

Fig. 241.



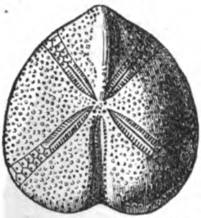
Ananchytes ovatus, Leske, ½. White chalk, upper and lower.

a. Side view. *b.* Base of the shell on which both the oral and anal apertures are placed; the anal being more round, and at the smaller end.

continent, on the other hand, where the Upper Cretaceous formations are so widely developed, true white chalk, in the ordinary sense of that term, does not exist.

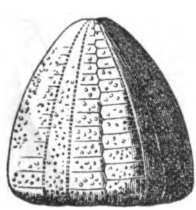
Fossils of the White Chalk.—Among the fossils of the white chalk, echinoderms are very numerous; and some of the genera, like *Ananchytes* (see fig. 241), are exclusively cretaceous.

Fig. 242.



Micraster cor-anguinum, Leske, ½. White chalk.

Fig. 243.

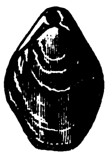


Galerites albogalerus, Lam., ½. White chalk.

Fig. 244.

Marsupites Milleri, Mant, ½. White chalk.

Fig. 245.

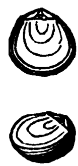


Terebratulina striata, Wahlenb., ½ Upper white chalk.

Fig. 246.

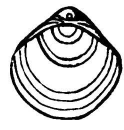
Rhynchonella octoplicata, Sow., ½. (Var. of *R. plicatilis*.) Upper white chalk.

Fig. 247.



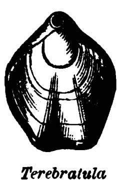
Magas pumila, Sow., nat. size. Upper white chalk.

Fig. 248.



Terebratula carnea Sow., ½. Upper white chalk

Fig. 249.

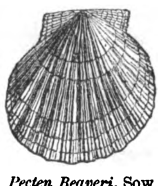


Terebratula biplicata, Brocchi, ½. Upper Cretaceous.

Fig. 250.

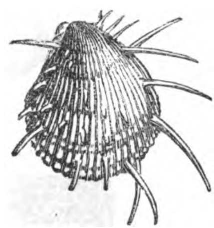
Crania Parisiensis, Duf., ⅜. Inferior, or attached valve. Upper white chalk.

Fig. 251.



Pecten Beaveri, Sow Reduced to one-third diameter. Lower white chalk, and chalk marl.

Fig. 252.

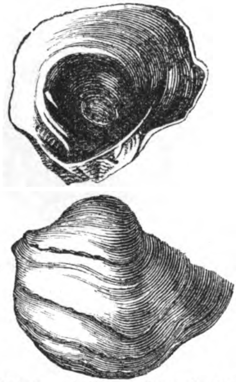


Lima spinosa, Sow. Syn. *Spondylus spinosus*, ½. Upper white chalk.

Among the Crinoidea, the *Marsupites* (fig. 244) is a characteristic genus. Among the mollusca, the cephalopoda are represented by Ammonites, Baculites (fig. 231, p. 269), and Belemnites (fig. 228, p. 266). Although there are eight or more species of Ammonites and six of them peculiar to it, this genus is much less fully represented than in each of the other subdivisions of the Upper Cretaceous group.

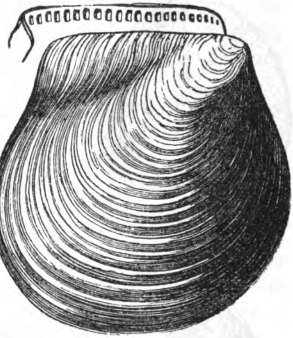
Among the brachiopoda in the white chalk, the *Terebratulæ* are very abundant (see figs. 245, 248, 249). With these are asso-

Fig. 253.



Ostrea vesicularis. Syn. *Gryphæa convexa*, ½.
Upper chalk and Upper greensand.

Fig. 254.



Inoceramus Lamarckii.
Syn. *Catillus Lamarckii*, ⅔.
White chalk (Dixon's Geol. Sussex, tab. 28, fig. 29).

Fig. 255.

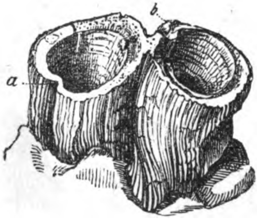


Fig. 256.

Fig. 257.

Fig. 258.

Radiolites Mortoni, Mantell. Houghton, Sussex. White chalk.
Diameter one-seventh nat. size.

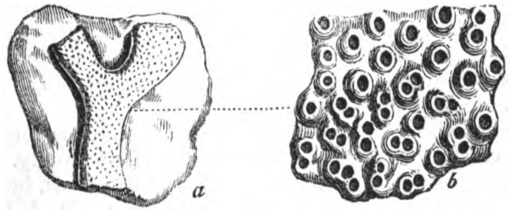
Fig. 255. Two individuals deprived of their upper valves, adhering together.
256. Same seen from above.
257. Transverse section of part of the wall of the shell, magnified to show the structure.
258. Vertical section of the same.

On the side where the shell is thinnest, there is one external furrow and corresponding internal ridge, *a*, *b*, figs. 255, 256; but they are usually less prominent than in these figures. The upper or opercular valve is wanting.

ciated some forms of oyster (see fig. 253), and other bivalves (figs. 251, 252).

Among the bivalve mollusca, no form marks the Cretaceous era in Europe, America, and India in a more striking manner

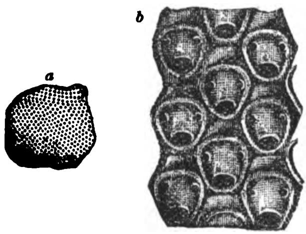
Fig. 259.



Eschara disticha. White chalk.
a. Natural size. *b.* Portion magnified.

than the extinct genus *Inoceramus* (*Catillus* of Lam.; see fig. 254), the shells of which are distinguished by a fibrous texture

Fig. 260.



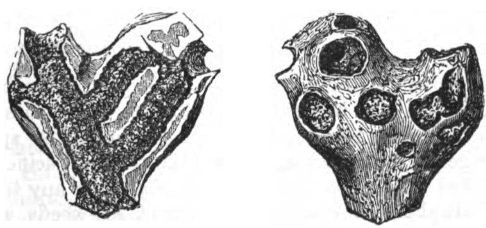
Escharina oceani.

a. Natural size.
b. Part of the same magnified.

White chalk.

and are often met with in fragments, having probably been extremely friable.

Fig. 261.



A branching sponge in a flint, from the white chalk.
From the collection of Mr. Bowerbank.

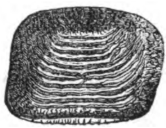
Of the singular order called *Rudistes*, by Lamarck, hereafter to be mentioned, as extremely characteristic of the chalk of Southern Europe, one species only (fig. 255) has been discovered in the white chalk of England.

The general absence of univalve mollusca in the white chalk

is very marked. Of polyzoa there is an abundance, such as *Eschara* and *Escharina* (figs. 259, 260). These and other organic bodies, especially sponges, such as *Ventriculites* (fig. 240, p. 275), are dispersed indifferently through the soft chalk and hard flint, and some of the flinty nodules owe their irregular forms to enclosed sponges, such as fig. 261, *a*, where the hollows in the exterior are caused by the branches of a sponge (fig. 261, *b*), seen on breaking open the flint.

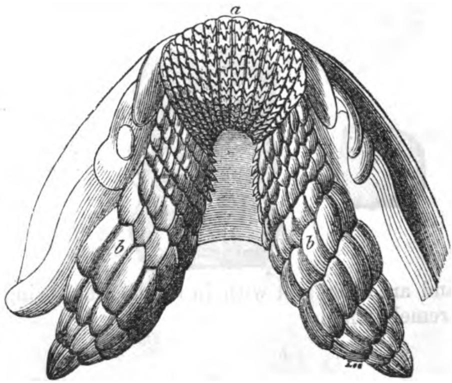
The remains of fishes of the Upper Cretaceous formations consist chiefly of teeth belonging to the shark family. Some of the genera are common to the Tertiary formations, but many are distinct. To the latter belongs the genus *Ptychodus* (fig. 262), which is allied to the living Port Jackson shark, *Cestracion Phillippi*, the anterior teeth of which (see fig. 263, *a*) are

Fig. 262.



Palatal tooth of *Ptychodus decurrens*, ⅔. Lower white chalk, Maidstone.

Fig. 263.



Cestracion Phillippi; recent. Port Jackson. Buckland. Bridgwater Treatise, Pl. 27, *d*.

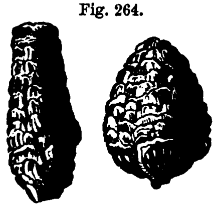
sharp and cutting, while the posterior or palatal teeth (*b*) are flat (fig. 262). The teleostean division, to which most of the living bony fishes belong, are also represented by species of Beryx, a genus still existing in the Atlantic and Pacific Oceans. But we meet with no bones of land animals, nor any terrestrial or fluviatile shells, nor any plants, except sea-weeds, and here and there a piece of drift-wood. All the appearances concur in leading us to conclude that the white chalk was the product of an open sea of considerable depth.

The existence of turtles and oviparous saurians, and of a Pterodactyl or winged lizard, found in the white chalk of Maidstone, implies, no doubt, some neighbouring land; but a few small islets in mid-ocean, like Ascension, formerly so much

frequented by migratory droves of turtle, might perhaps have afforded the required retreat where these creatures laid their eggs in the sand, or from which the flying species may have been blown out to sea. Of the vegetation of such islands we have scarcely any indication, but it consisted partly of cycadaceous plants; for a fragment of one of these was found by Capt. Ibbetson in the Chalk Marl of the Isle of Wight, and is referred by A. Brongniart to *Clathraria Lyellii* (Mantell), a species common to the antecedent Wealden period. The fossil plants, however, of beds corresponding in age to the white chalk at Aix-la-Chapelle, presently to be described, like the sandy beds of Saxony, before alluded to (p. 276), afford such evidence of land as to prove how vague must be any efforts of ours to restore the geography of that period.

The Pterodactyl of the Kentish Chalk, above alluded to, was of gigantic dimensions, measuring 16 feet 6 inches from tip to tip of its outstretched wings. Some of its elongated bones were at first mistaken by able anatomists for those of birds; of which class no osseous remains have as yet been derived from the white chalk, although they have been found (as will be seen at page 283) in the Chloritic sand.

Fig. 264.



Coprolites of fish, from the chalk.

The collector of fossils from the white chalk was formerly puzzled by meeting with certain bodies which were called larch-cones, which were afterwards recognised by Dr. Buckland to be the excrement of fish (see fig. 264). They are composed in great part of phosphate of lime.

Lower White Chalk.—The Lower White Chalk, which is several hundred feet thick, without flints, has yielded 25 species

Fig. 265.

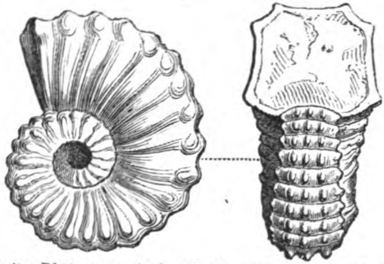
Baculites anceps, Lam., ½. Lower chalk.

of Ammonites, of which half are peculiar to it. The genera Baculite, Hamite, Scaphite, Turrilite, Nautilus, Belemnitella, and Belemnite, are also represented.

Chalk Marl.—The lower chalk without flints passes gradually downwards, in the South of England, into an argillaceous limestone, 'the chalk marl,' already alluded to (p. 266). It contains 32 species of Ammonites, 7 of which are peculiar to it, while 11 pass up into the overlying lower white chalk. *A. Rhotomagensis* (fig. 266) is characteristic of this formation. Among the British cephalopods of other genera may be mentioned

Scaphites æqualis (fig. 268) and the spiral and sinistral *Turrilites costatus* (fig. 267).

Fig. 266.



Ammonites Rhotomagensis, ⅓. Chalk marl. Back and side view.

Fig. 267.

Fig. 268.

Scaphites æqualis, ½.
Chloritic marl and sand
Dorsetshire.

a

Turrilites costatus, ½. Lower chalk and chalk marl.
a. Section, showing the foliated border of the sutures of the chambers.

Chloritic series (or Upper Greensand).—According to the old nomenclature, this subdivision of the chalk was called Upper Greensand, in order to distinguish it from those members of the Neocomian or Lower Cretaceous series below the Gault to which the name of Greensand had been applied. Besides the reasons before given (p. 265) for abandoning this nomenclature, it is objectionable in this instance as leading the uninitiated to suppose that the divisions thus named, Upper and Lower Greensand, are of co-ordinate value, instead of which the chloritic sand is quite a subordinate member of the Upper Cretaceous group, and the term Greensand has very commonly been used for the whole of the Lower Cretaceous rocks, which are almost

comparable in importance to the entire Upper Cretaceous series. The higher portion of the Chloritic series in some districts has been called chloritic marl, from its consisting of a chalky marl with chloritic grains. In parts of Surrey where calcareous matter is largely intermixed with sand, it forms a stone called malm-rock or fire-stone. In the cliffs of the southern coast of the Isle of Wight it contains bands of calcareous limestone with nodules of chert.

Coprolite bed.—The so-called coprolite bed, found near Farnham, in Surrey, and near Cambridge, contains nodules of phosphate of lime in such abundance as to be largely worked for the manufacture of artificial manure. It belongs to the lower part of the chloritic series, and is doubtless chiefly of animal origin, and may perhaps be partly coprolitic, derived from the excrement of fish and reptiles. The late Mr. Barrett discovered in it, near Cambridge, in 1858, the remains of a bird, which was rather larger than the common pigeon, and probably of the order Natatores, and which, like most of the Gull tribe, had well-developed wings. Portions of the tibia, femur, and some other bones have been detected, and the determinations of Mr. Barrett have been confirmed by Professor Owen.

The phosphatic bed in the suburbs of Cambridge must have been formed partly by the denudation of pre-existing rocks of

Fig. 269.

Ostrea columba.
Syn. *Gryphæa Columba*, ⅓.
Chloritic sand.

Fig. 270.

Ostrea carinata, ½.
Chalk marl and chloritic sand. Neocomian.

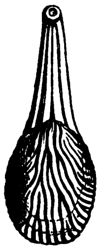
Cretaceous age. The fossil shells and bones of animals washed out of these denuded strata, especially the Gault, now forming a layer only a few feet thick, have yielded a rich harvest to the collector. A large Radiolite of the order Rudistes, no less than two feet in height, may be seen in the Cambridge Museum, obtained from this bed. The number of reptilian remains, all apparently of Cretaceous age, is truly surprising; more than ten species of Pterodactyle, five or six of Ichthyosaurus, one of Pliosaurus, one of Dinosaurus, eight of Chelonian, besides other forms, having been recognised.

The chloritic sand is regarded by many geologists as a littoral

deposit of the Chalk Ocean, and, therefore, contemporaneous with part of the chalk marl, and even, perhaps, with some part of the white chalk. For, as the land went on sinking, and the cretaceous sea widened its area, white mud and chloritic sand were always forming somewhere, but the line of sea-shore was perpetually shifting its position. Hence, though both sand and mud originated simultaneously, the one near the land, the other far from it, the sands in every locality where a shore became submerged might constitute the underlying deposit.

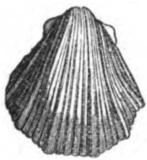
Among the characteristic mollusca of the chloritic sand may be mentioned *Terebrirostra lyra* (fig. 271), *Lima* (*Plagiostoma*) *Hoperi* (fig. 273), *Pecten quinquecostatus* (fig. 272), and *Ostrea columba* (fig. 269).

Fig. 271.



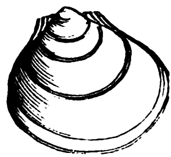
Terebrirostra lyra, Sow., ½. Chloritic sand and marl.

Fig. 272.



Pecten 5-costatus, ½. Lower white chalk and chloritic series.

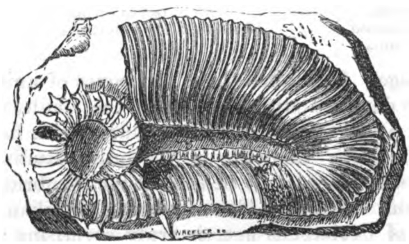
Fig. 273.



Lima (*Plagiostoma*) *Hoperi*, Sow ½. Syn. *Lima Hoperi*. White chalk and chloritic marl.

The cephalopoda are abundant, among which 40 species of Ammonites are now known, 10 being peculiar to this sub-division, and the rest common to the beds immediately above or below.

Fig. 274.



Ancyloceras spinigerum, D'Orb. Syn. *Hamites spiniger*, Sow. Near Folkestone. Gault.

Gault.—The lowest member of the Upper Cretaceous group, usually about 100 feet thick in the S.E. of England, is provin-

cially termed Gault. It consists of a dark blue marl, sometimes intermixed with greensand. Many peculiar forms of cephalopoda, such as *Hamites* (fig. 274), and *Scaphites*, with remarkable *Ammonites* and other fossils, characterise this formation, which, small as is its thickness, can be traced by its organic remains to distant parts of Europe, as, for example, to the Alps.

Twenty-one species of Ammonites are recorded as found in the Gault of England, of which only 8 are peculiar to it, 10 being common to the overlying Chloritic series.

Connection between Upper and Lower Cretaceous strata —Blackdown Beds.—The break between the Upper and Lower Cretaceous formations will be appreciated when it is stated that, although the Neocomian contains 31 species of Ammonites, and the Gault, as we have seen, 21, there are only 3 of these common to both divisions. Nevertheless, we may expect the discovery in England, and still more when we extend our survey to the Continent, of beds of passage intermediate between the Upper and Lower Cretaceous. Even now the Blackdown beds in Devonshire, which rest immediately on Triassic strata, and which evidently belong to some part of the Cretaceous series, have been referred by some geologists to the Upper group, by others to the Lower or Neocomian. They resemble the Folkestone beds of the latter series in mineral character, and 59 out of 156 of their fossil mollusca are common to them; but they have also 16 species common to the Gault, and 20 to the overlying Chloritic series; and, what is very important, out of 7 Ammonites 6 are found also in the Gault and Chloritic series, only 1 being peculiar to the Blackdown beds.

Professor Ramsay has remarked that there is a stratigraphical break; for in Kent, Surrey, and Sussex, at those few points where there are exposures of junctions of the Gault and Neocomian, the surface of the latter has been much eroded or denuded, while to the westward of the great chalk escarpment the unconformability of the two groups is equally striking. At Blackdown this unconformability is still more marked, for, though distant only 100 miles from Kent and Surrey, no formation intervenes between these beds and the Trias; all intermediate groups, such as the Lower Neocomian and Oolite, having either not been deposited or destroyed by denudation.

Flora of the Upper Cretaceous period.—As the Upper Cretaceous rocks of Europe are, for the most part, of purely marine origin, and formed in deep water usually far from the nearest shore, land-plants of this period, as we might naturally have anticipated, are very rarely met with. In the neighbourhood of Aix-la-Chapelle, however, an important exception occurs, for

there certain white sands and laminated clays, 400 feet in thickness, contain the remains of terrestrial plants in a beautiful state of preservation. These beds are the equivalents of the white chalk and chalk marl of England, or Sénonien of D'Orbigny, although the white siliceous sands of the lower beds, and the green grains in the upper part of the formation, cause it to differ in mineral character from our white chalk.

Beds of fine clay, with fossil plants, and with seams of lignite, and even perfect coal, are intercalated. Floating wood, containing perforating shells, such as Pholas and Gastrochœna, occur. There are likewise a few beds of a yellowish brown limestone, with marine shells, which enable us to prove that the lowest and highest plant beds belong to one group. Among these shells are *Pecten quadricostatus*, and several others which are common to the upper and lower part of the series, and *Trigonia limbata* (D'Orbigny), a shell of the white chalk; and a Hamite, a form so characteristic of the Cretaceous formation, was recognised in 1873 by Prof. Hughes in M. Debey's collection. On the whole the organic remains and the geological position of the strata prove distinctly that in the neighbourhood of Aix-la-Chapelle a gulf of the ancient Cretaceous sea was bounded by land composed of Devonian and Carboniferous rocks. These rocks consisted of quartzose and schistose beds, the first of which supplied white sand and the other argillaceous mud to a river which entered the sea at this point, carrying down in its turbid waters much drift-wood and the leaves of plants. Occasionally, when the force of the river abated, marine shells of the genera *Trigonia*, *Turritella*, *Pecten*, *Hamites*, &c., established themselves in the same area, and plants allied to *Zostera* and *Fucus* grew on the bottom.

The fossil plants of this member of the upper chalk at Aix have been diligently collected and studied by Dr. Debey, and as they afford the only example yet known of a terrestrial flora older than the Eocene, having the great divisions of the vegetable kingdom represented in nearly the same proportions as in our own times, they deserve particular attention. Dr. Debey estimates the number of species as amounting to more than 400, of which 70 or 80 are cryptogamous, chiefly ferns, 20 species of which can be well determined, most of them being in fructification. The scars on the bark of one or two are supposed to indicate tree-ferns. Of thirteen genera three are still existing, namely *Gleichenia*, now inhabiting the Cape of Good Hope and New Holland; *Lygodium*, now spread extensively through tropical regions, but having some species which live in Japan and North America; and *Asplenium*, a living cosmopolite form.

Among the phænogamous plants, the Conifers are abundant, the most common belonging to a genus called Cycadopsis by Debey, and hardly separable from Sequoia (or Wellingtonia), of which both the cones and branches are preserved. When I visited Aix, I found the silicified wood of this plant very plentifully dispersed through the white sands in the pits near that city. In one silicified trunk 200 rings of annual growth could be counted. Species of Araucaria like those of Australia are also found, and among the Monocotyledons there are some very peculiar types. No palms have been recognised with certainty, but 3 or 4 species of the genus Pandanus, or screw-pine, have been distinctly made out. The number of the Dicotyledonous Angiosperms is the most striking feature in so ancient a flora.[6]

Among them we find the familiar forms of the Oak (Cupuliferæ), the bog-myrtle (Myricaceæ) together with several genera of the Myrtaceæ. But the predominant order is the Proteaceæ, of which there are between 60 and 70 supposed species, some of extinct genera, but some referred to the following living forms—Dryandra, Grevillea, Hakea, Bellendina, Banksia, Persoonia—all now belonging to Australia, and Leucospermum, species of which form small bushes at the Cape.

The epidermis of the leaves of many of these Aix plants, especially of the Proteaceæ, is so perfectly preserved in an envelope of fine clay, that under the microscope the stomata, or breathing pores, can be detected, and their peculiar arrangement is identical with that known to characterise some living Proteaceæ (Grevillea, for example). Although this peculiarity of the structure of stomata is also found in plants of widely distant orders, it is, on the whole, but rarely met with, and, being thus

[6] In this and subsequent remarks on fossil plants I shall often use Dr. Lindley's terms, as most familiar in this country; but as those of M. A. Brongniart are much cited, it may be useful to geologists to give a table explaining the corresponding names of groups so much spoken of in palæontology.

	Brongniart.	Lindley.	
Cryptogamic.	1. Cryptogamous amphigens, or cellular cryptogamic.	Thallogens.	Lichens, sea-weeds, fungi.
	2. Cryptogamous acrogens.	Acrogens.	Mosses, equisetums, ferns, lycopodiums,—Lepidodendra.
Phænerogamic.	3. Dicotyledonous gymnosperms.	Gymnogens.	Cocifers and Cycads.
	4. Dicot. Angiosperms.	Exogens.	Compositæ, leguminosæ, umbelliferæ, cruciferæ, heaths, &c. All native European trees except Conifers.
	5. Monocotyledons, grasses, &c.	Endogens.	Palms, lilies, aloes, rushes.

observed to characterise a foliage previously suspected to be proteaceous, it adds to the probability that the botanical evidence had been correctly interpreted.

An occasional admixture at Aix-la-Chapelle of Fucoids and Zosterites attests, like the shells, the presence of salt water. Of insects, Dr. Debey has obtained about ten species of beetles of the families Curculionidæ and Carabidæ.

The resemblance of the flora of Aix-la-Chapelle to the tertiary and living floras in the proportional number of dicotyledonous angiosperms as compared to the gymnogens, is a subject of no small theoretical interest, because we can now affirm that these Aix plants flourished before the rich reptilian fauna of the secondary rocks had ceased to exist. The Ichthyosaurus, Pterodactyl, and Mosasaurus were of coeval date with the oak and Myrica. Speculations have often been hazarded respecting a connection between the rarity of Exogens in the older rocks and a peculiar state of the atmosphere. A denser air, it was suggested, had in earlier times been alike adverse to the well-being of the higher order of flowering plants, and of the quick-breathing animals, such as mammalia and birds, while it was favourable to a cryptogamic and gymnospermous flora, and to a predominance of reptile life. But we now learn that there is no incompatibility in the co-existence of a vegetation like that of the present globe, and some of the most remarkable forms of the extinct reptiles of the age of gymnosperms.

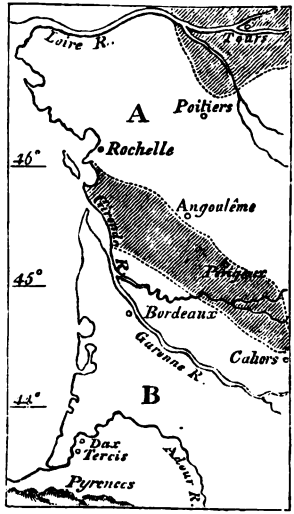
If the break between the flora of the Upper Cretaceous period and that of the Lower or Neocomian, as represented by the Wealden flora, seem at present to be somewhat sudden, the abruptness of the change will probably disappear when we are better acquainted with the fossil vegetation of the lowest strata of the Gault and that of the uppermost beds of the antecedent Neocomian.

Hippurite limestone.—*Difference between the chalk of the North and South of Europe.* By the aid of the three tests, superposition, mineral character, and fossils, the geologist has been enabled to refer to the same Cretaceous period certain rocks in the North and South of Europe, which differ greatly both in their fossil contents and in their mineral composition and structure.

If we attempt to trace the cretaceous deposits from England and France to the countries bordering the Mediterranean, we perceive, in the first place, that in the neighbourhood of London and Paris they form one great continuous mass, the Straits of Dover being a trifling interruption, a mere valley with chalk cliffs on both sides. We then observe that the main body of the

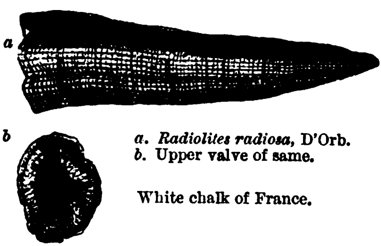
chalk which surrounds Paris stretches from Tours to near Poitiers (see the annexed map, fig. 275, in which the shaded part represents chalk).

Fig. 275.



Between Poitiers and La Rochelle, the space marked A on the map separates two regions of chalk. This space is occupied by the Oolite and certain other formations older than the Chalk and Neocomian, and has been supposed by M. E. de Beaumont to have formed an island in the Cretaceous sea. South of this space we again meet with rocks which we at once recognise to be cretaceous, partly from the chalky matrix and partly from the fossils being very similar to those of the white chalk of the north: especially certain species of the genera *Spatangus*, *Ananchytes*, *Cidaris*, *Nucula*, *Ostrea*, *Gryphæa* (*Exogyra*), *Pecten*, *Lima*, *Trigonia*, *Catillus* (*Inoceramus*) and *Terebratula*.[7] But Ammonites, as M. D'Archiac observes, of which so many species are met with in the chalk of the

Fig. 276.



a. *Radiolites radiosa*, D'Orb.
b. Upper valve of same.

White chalk of France.

Fig. 277.

Radiolites foliaceus, D'Orb
Syn. *Sphærulites agariciformis*, Blainv.
White chalk of Franec.

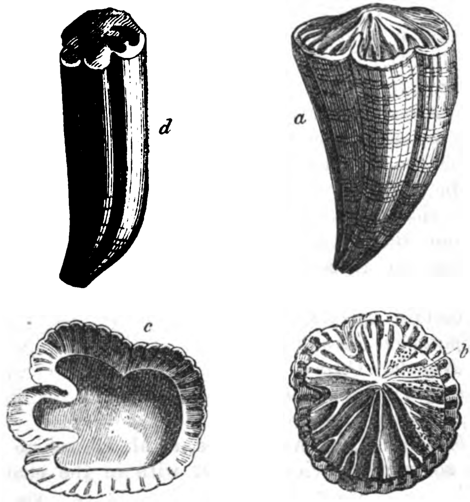
North of France, are scarcely ever found in the southern region while the genera *Hamite*, *Turrilite*, and *Scaphite*, and perhaps *Belemnite*, are entirely wanting.

On the other hand, certain forms are common in the South which are rare or wholly unknown in the North of France.

[7] D'Archiac, Sur la Form. Crétacée du S.-O. de la France, Mém. de la Soc. Géol. de France, tom. ii.

Among these may be mentioned many *Hippurites*, *Sphærulites*, and other members of that great order of mollusca called *Rudistes* by Lamarck, to which nothing analogous has been discovered in the living creation, but which is characteristic of rocks of the Cretaceous era in the South of France, Spain, Sicily, Greece, and other countries bordering the Mediterranean. The species called *Hippurites organisans* (fig. 278) is

Fig. 278.



Hippurites organisans, Desmoulins.

Upper chalk: chalk marl of Pyrenees.[8]

a. Young individual; when full grown they occur in groups adhering laterally to each other.
b. Upper side of the upper valve, showing a reticulated structure in those parts, *b*, where the external coating is worn off.
c. Upper end or opening of the lower and cylindrical valve.
d. Cast of the interior of the lower conical valve.

more abundant than any other in the South of Europe; and the geologist should make himself well acquainted with the cast of the interior *d*, which is often the only part preserved in many compact marbles of the Upper Cretaceous period. The flutings on the interior of the Hippurite, which are represented on the cast by smooth rounded longitudinal ribs, and in some individuals attain a great size and length, are wholly unlike the markings on the exterior of the shell.

Cretaceous Rocks in the United States.—If we pass to the American continent, we find in the State of New Jersey

[8] D'Orbigny's Paléontologie française, pl. 533.

a series of sandy and argillaceous beds wholly unlike in mineral character to our Upper Cretaceous system; which we can, nevertheless, recognise as referable, palæontologically, to the same division.

That they were about the same age generally as the European chalk and Neocomian, was the conclusion to which Dr. Morton and Mr. Conrad came after their investigation of the fossils in 1834. The strata consist chiefly of greensand and green marl, with an overlying coral limestone of a pale yellow colour, and the fossils, on the whole, agree most nearly with those of the Upper European series, from the Maestricht beds to the Gault inclusive. I collected sixty shells from the New Jersey deposits in 1841, five of which were identical with European species—*Ostrea larva*, *O. vesicularis*, *Gryphæa costata*, *Pecten quinquecostatus*, *Belemnitella mucronata*. As some of these have the greatest vertical range in Europe, they might be expected more than any others to recur in distant parts of the globe. Even where the species were different, the generic forms, such as the Baculite and certain sections of Ammonites, as also the *Inoceramus* (see above, fig. 254, p. 278) and other bivalves, have a decidedly cretaceous aspect. Fifteen out of the sixty shells above alluded to were regarded by Professor Forbes as good geographical representatives of well-known cretaceous fossils of Europe. The correspondence, therefore, is not small, when we reflect that the part of the United States where these strata occur is between 3,000 and 4,000 miles distant from the chalk of Central and Northern Europe, and that there is a difference of ten degrees in the latitude of the places compared on opposite sides of the Atlantic. Fish of the genera *Lamna*, *Galeus*, and *Carcharodon* are common to New Jersey and the European cretaceous rocks. So also is the genus *Mosasaurus* among reptiles. Professor O. C. Marsh has described five species of birds from the greensand of New Jersey; and he has discovered in the Upper Cretaceous shale of Kansas a remarkable adult bird about the size of a pigeon, and probably aquatic, to which he gives the name of *Ichthyornis dispar*. This bird approaches the reptilian type in possessing biconcave vertebræ, and well-developed teeth in both jaws.[9]

It appears from the labours of Dr. Newberry and others, that the Cretaceous strata of the United States east and west of the Appalachians are characterised by a flora, decidedly analogous to that of Aix-la-Chapelle above mentioned, and therefore having considerable resemblance to the vegetation of the Tertiary and Recent periods.

[9] American Journ. of Science, vol. v., Feb. 1873.

CHAPTER XVIII.

LOWER CRETACEOUS OR NEOCOMIAN FORMATION.

Classification of marine and freshwater strata—Upper Neocomian—Folkestone and Hythe beds—Atherfield clay—Similarity of conditions causing reappearance of species after short intervals—Upper Speeton clay—Middle Neocomian—Tealby series—Middle Speeton clay—Lower Neocomian—Lower Speeton clay—Wealden formation—Freshwater character of the Wealden—Weald clay—Hastings sand—Punfield beds of Purbeck, Dorsetshire—Fossil shells and fish of the Wealden—Area of the Wealden—Flora of the Wealden.

We now come to the Lower Cretaceous formation which was formerly called Lower Greensand, and for which it will be useful for reasons before explained (p. 265) to use the term 'Neocomian.'

LOWER CRETACEOUS OR NEOCOMIAN GROUP.

Marine.	Freshwater.
1. Upper Neocomian—Greensand of Folkestone, Sandgate and Hythe, Atherfield clay, upper part of Speeton clay. 2. Middle Neocomian — Punfield marine bed, Tealby beds, middle part of Speeton clay. 3. Lower Neocomian—Lower part of Speeton clay.	Part of Wealden beds of Kent, Surrey, Sussex, Hants, and Dorset.

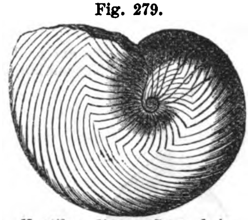
In Western France, the Alps, the Carpathians, Northern Italy, and the Apennines, an extensive series of rocks has been described by Continental geologists under the name of Tithonian. These beds, which are without any marine equivalent in this country, appear completely to bridge over the interval between the Neocomian and the Oolites. They may, perhaps, as suggested by Mr. Judd, be of the same age as part of the Wealden series.

UPPER NEOCOMIAN.

Folkestone and Hythe beds.—The sands which crop out beneath the Gault in Wiltshire, Surrey, and Sussex are sometimes in the uppermost part pure white, at others of a yellow and

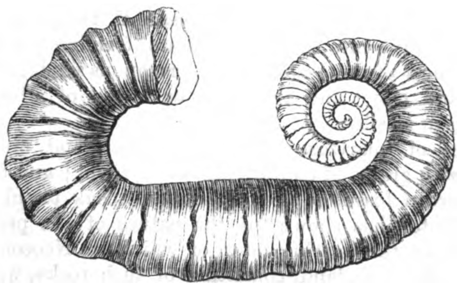
ferruginous colour, and some of the beds contain much green matter. At Hythe they contain layers of calcareous matter and chert, and at Maidstone and other parts of Kent, the limestone called Kentish Rag is intercalated. This somewhat clayey and calcareous stone forms strata two feet thick, alternating with quartzose sand. The total thickness of these Folkestone, Sandgate, and Hythe beds is less than 300 feet, and the Hythe beds are seen to rest immediately on a gray clay, to which we shall presently allude as the Atherfield clay. Among the fossils of the Hythe beds we may mention *Nautilus plicatus* (fig. 279), *Ancyloceras* (*Scaphites*) *gigas* (fig. 280), which has been aptly described as an Ammonite more or less uncoiled; *Trigonia caudata* (fig. 282), *Gervillia anceps* (fig. 281), a bivalve genus allied to Avicula, and *Terebratula sella* (fig. 283). In ferruginous beds of the same age in Wiltshire is found the remarkable shell called *Diceras Lonsdalii* (fig. 284, p. 294), which abounds in the Upper and Middle Neocomian of Southern Europe. This genus is closely allied to Chama, and the cast of the interior has been compared to the horns of a goat.

Fig. 279.



Nautilus plicatus, Sow., ½, in Fitton's Monog.

Fig. 280.



Ancyloceras gigas, D'Orb, ⅓.

Atherfield Clay.—We mentioned before that the Hythe series rests on a gray clay. This clay is only of slight thickness in Kent and Surrey, but acquires great dimensions at Atherfield in the Isle of Wight. The difference indeed in mineral character and thickness of the Upper Neocomian formation near Folkestone, and the corresponding beds in the south of the Isle

of Wight, about 100 miles distant, is truly remarkable. In the latter place we find no limestone answering to the Kentish Rag, and the entire thickness from the bottom of the Atherfield clay

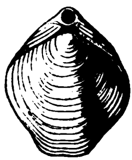
Fig. 281.

Gervillia anceps, Desh., ⅓.
Upper Neocomian, Surrey.

Fig. 282.

Trigonia caudata, Agass., ⅓.
Upper Neocomian.

Fig. 283.



Terebratula sella, Sow., ½.
Upper Neocomian, Hythe.

Fig. 284.

Diceras Lonsdalii, ⅓. Upper Neocomian, Wilts.
a. The bivalve shell.
b. Cast of one of the valves enlarged.

to the top of the Neocomian, instead of being less than 300 feet as in Kent, is given by the late Professor E. Forbes as 843 feet, which he divides into sixty-three strata, forming three groups. The uppermost of these consists of ferruginous sands; the second of sands and clay; and the third or lowest of a brown clay, abounding in fossils.

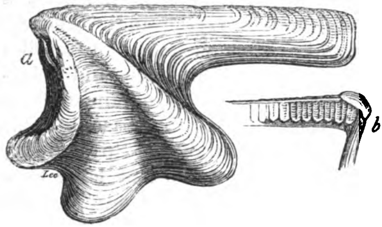
Pebbles of quartzose sandstone, jasper, and flinty slate, together with grains of chlorite and mica, occur; and fragments and waterworn fossils of the oolitic rocks speak plainly, as Mr. Godwin-Austen has shown, of the nature of the pre-existing formations, by the wearing down of which the Neocomian beds were formed. The land, consisting of such rocks, was doubtless submerged before the origin of the white chalk, a deposit which was formed in a more open and probably deeper sea, and in clearer waters.

Among the shells of the Atherfield clay the most abundant is the large *Perna Mulleti*, of which a reduced figure is here given (fig. 285).

Similarity of conditions causing reappearance of species.—Some species of mollusca and other fossils range through the whole

series, while others are confined to particular subdivisions, and Forbes laid down a law which has since been found of very general application in regard to estimating the chronological

Fig. 285.



Perna Mulleti, Desh., ⅓ nat. size.

a. Exterior.
b. Part of hinge-line of upper or right valve.

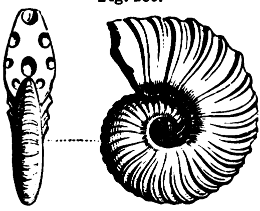
relations of consecutive strata. Whenever similar conditions, he says, are repeated, the same species reappear, provided too great a lapse of time has not intervened; whereas if the length of the interval has been geologically great, the same genera will reappear represented by distinct species. Changes of depth, or of the mineral nature of the sea-bottom, the presence or absence of lime or of peroxide of iron, the occurrence of a muddy, or a sandy, or a gravelly bottom, are marked by the banishment of certain species and the predominance of others. But these differences of conditions, being mineral, chemical, and local in their nature, have no necessary connection with the extinction, throughout a large area, of certain animals or plants. When the forms proper to loose sand or soft clay, or to perfectly clear water, or to a sea of moderate or great depth, recur with all the same species, we may infer that the interval of time has been, geologically speaking, small, however dense the mass of matter accumulated. But if, the genera remaining the same, the species are changed, we have entered upon a new period; and no similarity of climate, or of geographical and local conditions, can then recall the old species which a long series of destructive causes in the animate and inanimate world has gradually annihilated.

Speeton Clay, upper division.—On the coast beneath the white chalk of Flamborough Head, in Yorkshire, an argillaceous formation crops out, called the Speeton clay, several hundred feet in thickness, the palæontological relations of which have been ably worked out by Mr. John W. Judd;[1] and he has shown that it is separable into three divisions, the uppermost of which, 150 feet thick, and containing 87 species of mollusca,

[1] Judd, Speeton Clay, Quart. Geol. Journ. vol. xxiv. 1868 p. 218.

decidedly belongs to the Atherfield clay and associated strata of Hythe and Folkestone, already described. It is characterised by the *Perna Mulleti* (fig. 285) and *Terebratula sella* (fig. 283), and by *Ammonites Deshayesii* (fig. 286), a well-known Hythe and Atherfield fossil. Fine skeletons of reptiles of the genera Pliosaurus and Teleosaurus have been obtained from this clay. At the base of this upper division of the Speeton clay there occurs a layer of large Septaria, formerly worked for the manufacture of cement. This bed is crowded with fossils, especially Ammonites, one species of which, three feet in diameter, was observed by Mr. Judd.

Fig. 286.

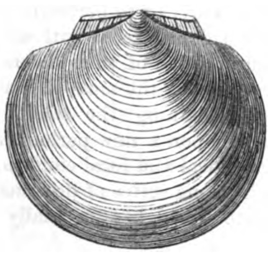


Ammonites Deshayesii, Leym., ½. Upper Neocomian.

MIDDLE NEOCOMIAN.

Tealby series.—At Tealby, a village in the Lincolnshire Wolds, there crops out beneath the white chalk some non-fossiliferous ferruginous sands about twenty feet thick, beneath which are beds of clay and limestone about fifty feet thick, with an interesting suite of fossils, among which are *Pecten cinctus* (fig. 287), from 9 to 12 inches in diameter, *Ancyloceras Duvallii* (fig. 288), and some 40 other shells, many of them common to the Middle Speeton clay, about to be mentioned. Mr. Judd remarks that as *Ammonites clypeiformis* and *Terebratula hippopus* characterise the Middle Neocomian of the Continent, it is to this

Fig. 287.



Pecten cinctus, Sow. (*P. crassitesta*, Röm.) Middle Neocomian, England; Middle and Lower Neocomian, Germany, ½ nat. size.

Fig. 288.

Ancyloceras (Crioceras) *Duvallii*, Leveillé. Middle and Lower Neocomian, ½ nat. size.

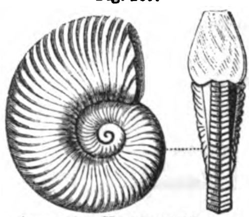
stage that the Tealby series containing the same fossils may be assigned.[2]

The middle division of the Speeton clay, occurring at Speeton below the cement-bed, before alluded to, is 150 feet thick and contains about 39 species of mollusca, half of which are common to the overlying clay. Among the peculiar shells, as before mentioned, *Ancyloceras* (*Crioceras*) *Duvallii* (fig. 288) and *Pecten cinctus* (fig. 287) occur.

LOWER NEOCOMIAN.

In the lower division of the Speeton clay, 200 feet thick, 46 species of mollusca have been found, and three divisions, each characterised by its peculiar ammonite, have been noticed by Mr. Judd. The central zone is marked by *Ammonites Noricus* (see fig. 289). On the Continent these beds are well known by their corresponding fossils, the Hils clay and conglomerate of the North of Germany agreeing with the Middle and Lower Speeton, the latter of which, with the same mineral characters and fossils as in Yorkshire, is also found in the little island of Heligoland. Yellow limestone, which I have myself seen near Neuchâtel, in Switzerland, represents the lower Neocomian at Speeton.

Fig. 289.



Ammonites Noricus, Schloth., nat. size. Lower Neocomian. Speeton.

WEALDEN FORMATION.

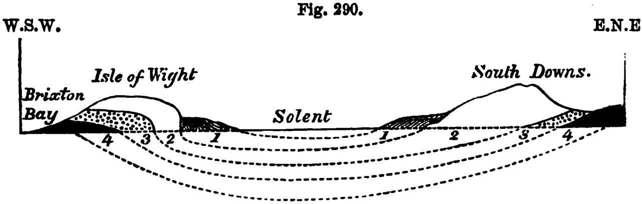
Beneath the Atherfield clay or Upper Neocomian of the S.E. of England, a freshwater formation is found, called the Wealden, which, although it occupies a small horizontal area in Europe, as compared to the White Chalk and the marine Neocomian beds, is nevertheless of great geological interest, since the imbedded remains give us some insight into the nature of the terrestrial fauna and flora of the Lower Cretaceous epoch. The name of Wealden was given to this group because it was first studied in parts of Kent, Surrey, and Sussex, called the Weald; and we are indebted to Dr. Mantell for having shown, in 1822, in his 'Geology of Sussex,' that the whole group was of fluviatile origin. In proof of this he called attention to the entire absence of Ammonites, Belemnites, Brachiopoda, Echinodermata, Corals, and other marine fossils, so characteristic of the Cretaceous rocks above, and of the Oolitic strata below, and to

[2] Judd, Quart. Geol. Journ. 1867, vol. xxiii. p. 249.

the presence in the Weald of Paludinæ, Melaniæ, Cyrenæ, and various fluviatile shells, as well as the bones of terrestrial reptiles and the trunks and leaves of land-plants.

The evidence of so unexpected a fact as that of a dense mass of purely freshwater origin underlying a deep-sea deposit (a phenomenon with which we have since become familiar) was received, at first, with no small doubt and incredulity. But the relative position of the beds is unequivocal; the Weald clay being distinctly seen to pass beneath the Atherfield clay in various parts of Surrey, Kent, and Sussex, and to reappear in the Isle of Wight at the base of the Cretaceous series, being, no doubt, continuous far beneath the surface, as indicated by the dotted lines in the annexed diagram (fig. 290). They are also

Fig. 290.



1. Tertiary. 2. Chalk and Gault. 3. Upper Neocomian (or Lower Greensand). 4. Wealden (Weald Clay and Hastings Sand).

found occupying the same relative position below the chalk in the peninsula of Purbeck, where, as we shall see in the sequel, they repose on strata referable to the Upper Oolite.

Weald Clay.—The upper division, or Weald clay, is, in great part, of freshwater origin, but in its highest portion contains beds of oysters and other marine shells which indicate fluvio-marine conditions. The uppermost beds are not only conformable, as Dr. Fitton observes, to the inferior strata of the overlying Neocomian, but of similar mineral composition. To explain this, we may suppose that, as the delta of a great river was tranquilly subsiding, so as to allow the sea to encroach upon the space previously occupied by fresh water, the river still continued to carry down the same sediment into the sea. In confirmation of this view it may be stated that the remains of the *Iguanodon Mantelli*, a gigantic terrestrial reptile, belonging to the order Dinosauria, and very characteristic of the Wealden, has been discovered near Maidstone, in the overlying Kentish Rag, or marine limestone of the Upper Neocomian. Hence we may infer that some of the saurians which inhabited the country of the great river continued to live when part of the district had become submerged beneath the sea. Thus, in our own times,

we may suppose the bones of large crocodiles to be frequently entombed in recent freshwater strata in the delta of the Ganges. But if part of that delta should sink down so as to be covered by the sea, marine formations might begin to accumulate in the same space where freshwater beds had previously been formed; and yet the Ganges might still pour down its turbid waters in the same direction, and carry seaward the carcases of the same species of crocodile, in which case their bones might be included in marine as well as in subjacent freshwater strata.

The Iguanodon, first discovered by Dr. Mantell, was an herbivorous reptile, of which the teeth, though bearing a great analogy, in their general form and crenated edges (see figs. 291, *a*, 291, *b*), to the modern Iguanas which now frequent the tropical woods of America and the West Indies, exhibit many important differences. It appears that they have often been worn by the process of mastication; whereas the existing herbivorous reptiles clip and gnaw off the vegetable productions on which they feed,

Fig. 291.

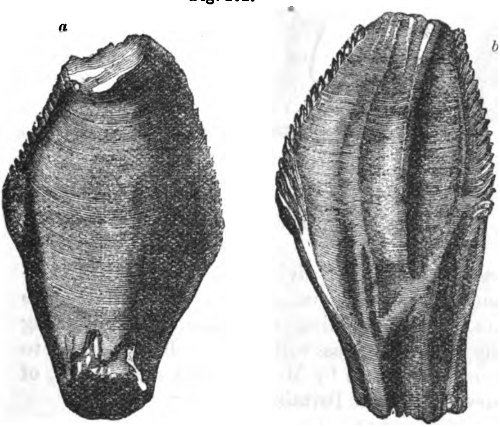


Fig. 292.

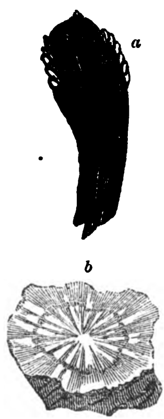


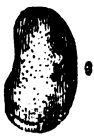
Fig. 291. *a*, *b*. Tooth of *Iguanodon Mantelli*, nat. size.
Fig. 292. *a*. Partially worn tooth of young individual of the same.
b. Crown of tooth in adult, worn down. (Mantell.)

but do not chew them. Their teeth frequently present an appearance of having been chipped off, but never, like the fossil teeth of the Iguanodon, have a flat ground surface (see fig. 292, *b*) resembling the grinders of herbivorous mammalia. Dr. Mantell computes that the teeth and bones of this species, which passed under his examination during twenty years, must have belonged to no less than seventy-one distinct individuals,

varying in age and magnitude from the reptile just burst from the egg, to one of which the femur measured twenty-four inches in circumference. Yet, notwithstanding that the teeth were more numerous than any other bones, it is remarkable that it was not until the relics of all these individuals had been found, that a solitary example of part of a jawbone was obtained. Soon afterwards remains both of the upper and lower jaw were met with in the Hastings beds in Tilgate Forest near Cuckfield. In the same sands at Hastings, Mr. Beckles found large tridactyle impressions which it is conjectured were made by the hind feet of this animal, on which it is ascertained that there were only three well-developed toes.

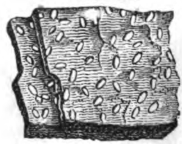
Occasionally bands of limestones called Sussex Marble occur in the Weald clay, almost entirely composed of a species of *Paludina*, closely resembling the common *P. vivipara* of English rivers. Shells of the *Cypris*, a genus of Crustaceans before mentioned (p. 33), as abounding in lakes and ponds, are also

Fig. 293.



Cypris spinigera, Fitton.

Fig. 294.



Weald clay, with Cyprides.

plentifully scattered through the clays of the Wealden, sometimes producing, like plates of mica, a thin lamination (see fig. 294).

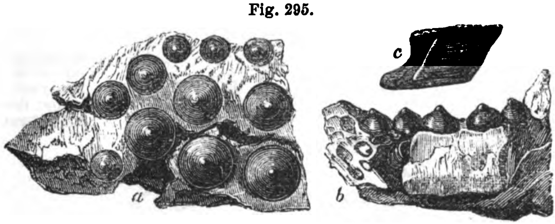
Hastings Sands.—This lower division of the Wealden consists of sand, sandstone, calciferous grit, clay, and shale; the argillaceous strata, notwithstanding the name, predominating somewhat over the arenaceous, as will be seen by reference to the following section, drawn up by Messrs. Drew and Foster, of the Geological Survey of Great Britain:—

	Names of Subordinate Formations.	Mineral Composition of the Strata.	Thickness in Feet.
Hastings Sand.	Tunbridge Wells Sand	Sandstone and loam	150
	Wadhurst Clay	Blue and brown shale and clay with a little calc-grit	100
	Ashdown Sand	Hard sand with some beds of calc-grit	160
	Ashburnham Beds	Mottled white and red clay with some sandstone	330

The picturesque scenery of the 'High Rocks' and other places in the neighbourhood of Tunbridge Wells is caused by the steep natural cliffs, to which a hard bed of white sand, occurring in the upper part of the Tunbridge Wells Sand, mentioned in the above table, gives rise. This bed of 'rock sand' varies in thickness from 25 to 48 feet. Large masses of it, which were by no means hard or capable of making a good building-stone, form, nevertheless, projecting rocks with perpendicular faces, and resist the degrading action of the river because, says Mr. Drew, they present a solid mass without planes of division. The calcareous sandstone and grit of Tilgate Forest, near Cuckfield, in which the remains of the Iguanodon and Hylæosaurus were first found by Dr. Mantell, constitute an upper member of the Tunbridge Wells Sand, while the 'sand rock' of the Hastings cliffs, about 100 feet thick, is one of the lower members of the same. The reptiles, which are very abundant in this division, consist partly of saurians, referred by Owen and Mantell to eight genera, among which, besides those already enumerated, we find the Megalosaurus and Plesiosaurus. The Pterodactyl also, a flying reptile, is met with in the same strata, and many remains of Chelonians of the genera *Trionyx* and *Emys*, now confined to tropical regions.

The fishes of the Wealden are chiefly referable to the Ganoid and Placoid orders. Among them the teeth and scales of

Fig. 295.



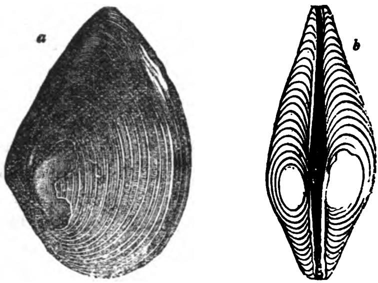
Lepidotus Mantelli, Agass. Wealden.
a. Palate and teeth. *b.* Side view of teeth. *c.* Scale.

Lepidotus are most widely diffused (see fig. 295). These ganoids were allied to the *Lepidosteus*, or Gar-pike, of the American rivers. The whole body was covered with large and very thick rhomboidal scales, having the exposed part coated with enamel. Most of the species of this genus are supposed to have been either river-fish, or inhabitants of the sea at the mouth of estuaries.

At different horizons in the Hastings Sand we find again and again slabs of sandstone with a strong ripple-mark, and between

these slabs beds of clay many yards thick. In some places, as at Stammerham, near Horsham, there are indications of this clay having been exposed so as to dry and crack before the next layer

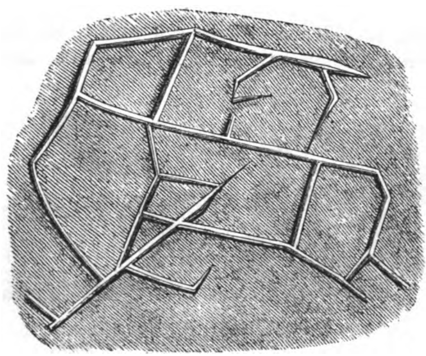
Fig. 296.



Unio Valdensis, Mant., ⅓.
Isle of Wight and Dorsetshire; in the lower beds of the Hastings Sands.

was thrown down upon it. The open cracks in the clay have served as moulds, of which casts have been taken in relief, and which are, therefore, seen on the lower surface of the sandstone (see fig. 297).

Fig. 297.



Underside of slab of sandstone about one yard in diameter. Stammerham, Sussex.

Near the same place a reddish sandstone occurs in which are innumerable traces of a fossil vegetable, apparently *Sphenopteris*, the stems and branches of which are disposed as if the plants were standing erect on the spot where they originally grew, the sand having been gently deposited upon and around them; and similar appearances have been remarked in other places in this formation.[3] In the same division also of the Wealden, at Cuckfield, is a bed of gravel or conglomerate, consisting of water-

[3] Mantell, Geol. of S.E. of England, p. 244.

worn pebbles of quartz and jasper, with rolled bones of reptiles. These must have been drifted by a current, probably in water of no great depth.

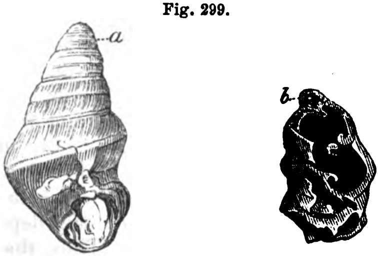
From such facts we may infer that, notwithstanding the great thickness of this division of the Wealden, the whole of it was a deposit in water of a moderate depth, and often extremely shallow. This idea may seem startling at first, yet such would be the natural consequence of a gradual and continuous sinking of the ground in an estuary or bay, into which a great river discharged its turbid waters. By each foot of subsidence, the fundamental rock would be depressed one foot farther from the surface; but the bay would not be deepened, if newly deposited mud and sand should raise the bottom one foot. On the contrary, such new strata of sand and mud might be frequently laid dry at low water, or overgrown for a season by a vegetation proper to marshes.

Fig. 298.

Sphenopteris gracilis, Fitton. From the Hastings Sands near Tunbridge Wells.
a. Portion of the same magnified.

Punfield beds, brackish and marine.—The shells of the Wealden beds belong to the genera *Melanopsis*, *Melania*, *Paludina*, *Cyrena*, *Cyclas*, *Unio* (see fig. 296), and others, which inhabit estuaries, rivers, or lakes; but one band has been found at Punfield, in Dorsetshire, indicating a brackish state of the

Fig. 299.



Vicarya Lujani, De Verneuil,[4] Wealden, Punfield.
a. Nearly perfect shell.
b. Vertical section of smaller specimen showing continuous ridges as in *Nerinæa*

water, where the genera *Corbula*, *Mytilus*, and *Ostrea* occur; and in some places this bed becomes purely marine, containing some well-known Neocomian fossils, among which *Ammonites*

[4] Foss. de Utrillas.

Deshayesii (fig. 286, p. 296) may be mentioned. Others are peculiar as British, but very characteristic of the Upper and Middle Neocomian of the North of Spain, and among these is conspicuous the *Vicarya Lujani* (fig. 299), a shell allied to Nerinæa. The middle Neocomian beds of Spain in which this shell abounds, attain at Utrillas a thickness of 530 feet, and contain ten beds of coal, lignite or jet, which are extensively worked.[5]

By reference to the table (p. 292) it will be seen that the Wealden beds are given as the freshwater equivalents of the Marine Neocomian. The highest part of them in England may, for reasons just given, be regarded as Upper Neocomian, while some of the inferior portions may correspond in age to the Middle and Lower divisions of that group. In favour of this latter view, M. Marcou mentions that a fish called *Asteracanthus granulosus*, occurring in the Tilgate beds, is characteristic of the lowest beds of the Neocomian of the Jura, and it is well known that *Corbula alata*, common in the Ashburnham beds, is found also at the base of the Neocomian of the Continent.

Area of the Wealden.—In regard to the geographical extent of the Wealden, it cannot be accurately laid down; because so much of it is concealed beneath the newer marine formations. It has been traced about 150 English miles from west to east, from the coast of Dorsetshire to near Boulogne, in France; and nearly 300 miles from north-west to south-east, from Surrey and Hampshire to Vassy, in France. If the formation be continuous throughout this space, which is very doubtful, it does not follow that the whole was contemporaneous; because, in all likelihood, the physical geography of the region underwent frequent changes throughout the whole period, and the estuary may have altered its form, and even shifted its place. Dr. Dunker, of Cassel, and H. von Meyer, in an excellent monograph on the Wealdens of Hanover and Westphalia, have shown that they correspond so closely, not only in their fossils, but also in their mineral characters, with the English series, that we can scarcely hesitate to refer the whole to one great delta. Even then, the magnitude of the deposit may not exceed that of many modern rivers. Thus, the delta of the Quorra or Niger, in Africa, stretches into the interior for more than 170 miles, and occupies, it is supposed, a space of more than 300 miles along the coast, thus forming a surface of more than 25,000 square miles, or equal to about one-half of England.[6] Besides, we know not, in such cases, how far the fluviatile sedi-

[5] Judd, Quart. Geol. Journ. vol. xxvii. 1871, p. 225.
[6] Fitton, Geol. of Hastings, p. 58, who cites Lander's Travel.

ment and organic remains of the river and the land may be carried out from the coast, and spread over the bed of the sea. I have shown, when treating of the Mississippi, that a more ancient delta, including species of shells such as now inhabit Louisiana, has been upraised, and made to occupy a wide geographical area, while a newer delta is forming;[7] and the possibility of such movements and their effects must not be lost sight of when we speculate on the origin of the Wealden.

It may be asked where the continent was placed, from the ruins of which the Wealden strata were derived, and by the drainage of which a great river was fed. If the Wealden were gradually going downwards 1,000 feet or more perpendicularly, a large body of fresh water would not continue to be poured into the sea at the same point. The adjoining land, if it participated in the movement, could not escape being submerged. But we may suppose such land to have been stationary, or even undergoing contemporaneous slow upheaval. There may have been an ascending movement in one region, and a descending one in a contiguous parallel zone of country. But, even if that were the case, it is clear that finally an extensive depression took place in that part of Europe where the deep sea of the Cretaceous period was afterwards brought in.

Thickness of the Wealden.—In the Weald area itself, between the North and South Downs, freshwater beds to the thickness of 1,600 feet are known, the base not being reached. Probably the thickness of the whole Wealden series, as seen in Swanage Bay, cannot be estimated at less than 2,000 feet.

Wealden Flora.—The flora of the Wealden is characterised by a great abundance of Coniferæ, Cycadeæ, and Ferns, and by the absence of leaves and fruits of dicotyledonous angiosperms. The discovery in 1855, in the Hastings beds of the Isle of Wight, of Gyrogonites, or spore-vessels of the Chara, was the first example of that genus of plants, so common in the Tertiary strata, being found in a Secondary or Mesozoic rock.

Lower Cretaceous Arctic flora.—A remarkable counterpart to this Lower Neocomian flora has been lately (1872) brought by Professor Nordenskiöld from Greenland, lat. 71° N., and Spitzbergen, lat. 78° N., the species having been determined by Professor Heer. The Greenland plants, among which are nine species of Cycads and 38 species of Ferns, agree very closely with the flora of the Lower Chalk of Europe, and have a decidedly sub-tropical aspect. Professor Heer mentions 13 species of ferns of the genus Gleichenia, many of them retaining

[7] See above, p. 81; and Second Visit to the U.S., vol. ii. chap. xxxiv.

even the fructification, and this genus is now almost exclusively tropical, although represented by a few rare species in New Zealand and Tasmania. Among the Spitzbergen plants, which are less numerous, the Sequoia Reichenbachii, common to the Lower Cretaceous of Greenland, is very abundant, one branch bearing the fruit. We cannot therefore doubt that the warm climate of the Cretaceous period extended to within 12° of the pole, though in the present state of our knowledge we are quite unable to frame any satisfactory theory as to the causes by which it was produced.

[In the third part of the 'Flora Arctica' (1875) Prof. Heer enumerates as many as 75 species of plants obtained from the Lower Cretaceous deposits of Greenland which appear to correspond with the Upper Neocomian of Europe. Of these, only one species is exogenous and is referred to the poplars. Prof. Heer contrasts this assemblage of plants with another fossil flora from near the same locality in Greenland and corresponding in age to the Chalk of Europe. Of the 68 species found, only 5 are common to the older flora, and these belong to the genera *Sequoia* and *Gleichenia* which have survived to the present day. In both deposits, Conifers and ferns appear to have predominated. But in the Upper Cretaceous flora fully half the total number of species belong to exogens, among others to the genera Populus, Myrica, Ficus, Sassafras, and Magnolia.]

CHAPTER XIX.

JURASSIC GROUP.—PURBECK BEDS AND OOLITE.

The Purbeck beds a member of the Jurassic group—Subdivisions of that group—Physical geography of the Oolite in England and France—Upper Oolite—Purbeck beds—New genera of fossil mammalia in the Middle Purbeck of Dorsetshire—Dirt-bed or ancient soil—Fossils of the Purbeck beds—Portland stone and fossils—Kimmeridge clay—Lithographic stone of Solenhofen—Archæopteryx—Middle Oolite—Coral rag—Nerinæa limestone—Oxford Clay, Ammonites and Belemnites—Kelloway rock—Lower, or Bath Oolite—Oolite and Bradford clay—Stonesfield slate—Fossil mammalia—Plants of the Oolite—Fuller's earth—Inferior Oolite and fossils—Northamptonshire slates—Yorkshire Oolitic coal-field—Brora coal—Palæontological relations of the several subdivisions of the Oolitic group.

Classification of the Oolite.—Immediately below the Hastings Sands we find in Dorsetshire another remarkable formation, called *the Purbeck*, because it was first studied in the sea-cliffs of the Peninsula of Purbeck in that county. These beds are for the most part of freshwater origin; but the organic remains of some few intercalated beds are marine, and show that the Purbeck series has a closer affinity to the Oolitic group, of which it may be considered as the newest or uppermost member.

In England generally, and in the greater part of Europe, both the Wealden and Purbeck beds are wanting, and the marine Cretaceous group is followed immediately, in the descending order, by another series called the Jurassic. In this term, the formations commonly designated as "the Oolite and Lias" are included, both being found in the Jura Mountains. The Oolite was so named because, in the countries where it was first examined, the limestones belonging to it had an Oolitic structure (see p. 13). These rocks occupy in England a zone nearly thirty miles in average breadth, which extends across the island, from Yorkshire in the north-east to Dorsetshire in the south-west. Their mineral characters are not uniform throughout this region; but the following are the names of the principal subdivisions observed in the central and south-eastern parts of England:—

OOLITE.

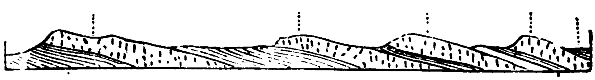
Upper	*a.* Purbeck beds. *b.* Portland oolite (stone) and sand. *c.* Kimmeridge clay.
Middle	*d.* Coral rag. *e.* Oxford clay, and Kelloway rock.
Lower	*f.* Cornbrash and Forest marble. *g.* Great Oolite and Stonesfield slate. *h.* Fuller's earth. *i.* Inferior Oolite.

The Upper Oolitic system of the above table has usually the Kimmeridge clay for its base; the Middle Oolitic system, the Oxford clay. The Lower system reposes on the Lias, an argillo-calcareous formation, which some include in the Lower Oolite, but which will be treated of separately in the next chapter. Many of these subdivisions are distinguished by peculiar organic remains; and, though varying in thickness, may be traced in certain directions for great distances, especially if we compare the part of England to which the above-mentioned type refers with the north-east of France and the Jura Mountains adjoining. In that country, distant above 400 geographical miles, the analogy to the accepted English type, notwithstanding the thinness or occasional absence of the clays, is more perfect than in Yorkshire or Normandy.

Physical Geography.—The alternation, on a grand scale, of distinct formations of clay and limestone has caused the oolitic and liassic series to give rise to some marked features in the physical outline of parts of England and France. Wide valleys can usually be traced throughout the long bands of country where the argillaceous strata crop out; and between these valleys the limestones are observed, forming ranges of hills or more elevated grounds. These ranges terminate abruptly on the side on which the several clays rise up from beneath the calcareous strata.

The annexed cut will give the reader an idea of the configuration of the surface now alluded to, such as may be seen in

Fig. 300.



passing from London to Cheltenham, or in other parallel lines from east to west, in the southern part of England. It has

been necessary, however, in this drawing, greatly to exaggerate the inclination of the beds, and the height of the several formations, as compared to their horizontal extent. It will be remarked, that the lines of steep slope, or escarpment, face towards the west in the great calcareous eminences formed by the Chalk and the Upper, Middle, and Lower Oolites; and at the base of which we have respectively the Gault, Kimmeridge clay, Oxford clay, and Lias. This last forms, generally, a broad vale at the foot of the escarpment of inferior Oolite; but where it acquires considerable thickness, and contains solid beds of marlstone, it occupies the lower part of the escarpment.

The external outline of the country which the geologist observes in travelling eastward from Paris to Metz, is precisely analogous, and is caused by a similar succession of rocks intervening between the tertiary strata and the Lias; with this difference, however, that the escarpments of Chalk, and Upper, Middle, and Lower Oolites face towards the east instead of the west. It is evident, therefore, that the denuding causes (see p. 85) have acted similarly over an area several hundred miles in diameter, removing the softer clays more extensively than the limestones, and causing these last to form steep slopes or escarpments wherever the harder calcareous rock was based upon a more yielding and destructible formation.

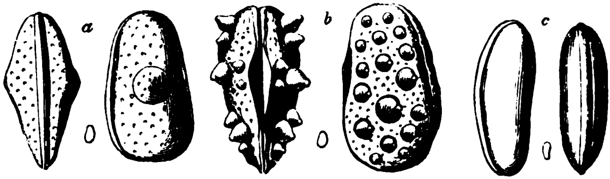
UPPER OOLITE.

Purbeck beds.—These strata, which we class as the uppermost member of the Oolite, are of limited geographical extent in Europe, as already stated, but they acquire importance when we consider the succession of three distinct sets of fossil remains which they contain. Such repeated changes in organic life must have reference to the history of a vast lapse of ages. The Purbeck beds are finely exposed to view in Durdlestone Bay, near Swanage, Dorsetshire, and at Lulworth Cove and the neighbouring bays between Weymouth and Swanage. At Meup's Bay, in particular, Professor E. Forbes examined minutely, in 1850, the organic remains of this group, displayed in a continuous sea-cliff section; and it appears from his researches that the Upper, Middle, and Lower Purbecks are each marked by peculiar species of organic remains, these again being different, so far as a comparison has yet been instituted, from the fossils of the overlying Hastings Sands and Weald Clay.

Upper Purbeck.—The highest of the three divisions is purely freshwater, the strata, about fifty feet in thickness, containing shells of the existing genera *Paludina*, *Physa*, *Limnæa*, *Planorbis*,

Valvata, Cyclas, Unio, with *Cyprides* and fish. All the species seem peculiar, and among these the *Cyprides* are very abundant and characteristic. (See fig. 301, *a, b, c.*)

Fig. 301.



Cyprides from the Upper Purbecks.
a. Cypris gibbosa, E. Forbes. *b. Cypris tuberculata*, E. Forbes.
c. Cypris leguminella, E. Forbes.

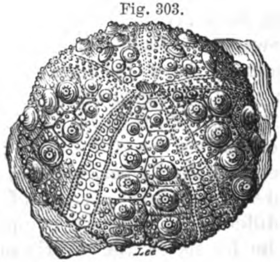
The stone called 'Purbeck Marble,' formerly much used in ornamental architecture in the old English cathedrals of the southern counties, is exclusively procured from this division.

Middle Purbeck.—Next in succession is the Middle Purbeck, about thirty feet thick, the uppermost part of which consists of freshwater limestone, with cyprides, turtles, and fish of different species from those in the preceding strata. Below the limestone are brackish-water beds full of *Cyrena*, and traversed by bands abounding in *Corbula* and *Melania.* These are based on a purely marine deposit, with *Pecten*, *Modiola*, *Avicula*, and *Thracia.* Below this, again, come limestones and shales, partly of brackish and partly of freshwater origin, in which many fish, especially species of *Lepidotus* and *Microdon radiatus*, are found, and a crocodilian reptile named *Macrorhynchus.* Among the mollusks, a remarkable ribbed *Melania*, of the subgenus *Chilina*, occurs.

Fig. 302.

Ostrea distorta, Sow., nat. size.
Cinder-bed, Middle Purbeck.

Fig. 303.

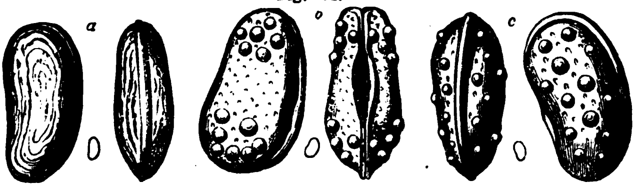


Hemicidaris Purbeckensis, E. Forbes, nat. size. Middle Purbeck.

Immediately below is a great and conspicuous stratum, twelve feet thick, formed of a vast accumulation of shells of

Ostrea distorta (fig. 302), long familiar to geologists under the local name of 'Cinder-bed.' In the uppermost part of this bed Professor Forbes discovered the first echinoderm (fig. 303) as yet known in the Purbeck series, a species of *Hemicidaris*, a genus characteristic of the Oolitic period, and scarcely, if at all, distinguishable from a previously known Oolitic fossil. It was accompanied by a species of *Perna*. Below the Cinder-bed freshwater strata are again seen, filled in many places with species of *Cypris* (fig. 304, *a*, *b*, *c*), and with *Valvata*, *Paludina*,

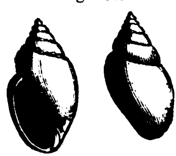
Fig. 304.



Cyprides from the Middle Purbecks.
a. Cypris striato-punctata, E. Forbes. *b. Cypris fasciculata*, E. Forbes.
c. Cypris granulata, Sow.

Planorbis, *Limnæa*, *Physa* (fig. 305), and *Cyclas*, all different from any occurring higher in the series. It will be seen that *Cypris fasciculata* (fig. 304, *b*) has tubercles at the end only of each valve, a character by which it can be immediately recognised. In fact, these minute crustaceans, almost as frequent in some of the shales as plates of mica in a micaceous sandstone, enable geologists at once to identify the Middle Purbeck in places far from the Dorsetshire cliffs, as for example, in the Vale of Wardour, in Wiltshire. Thick beds of chert occur in the Middle Purbeck filled with mollusca and cyprides of the genera already enumerated, in a beautiful state of preservation, often converted into chalcedony. Among these Professor Forbes met with gyrogonites (the spore-vessels of *Chara*), plants never before discovered in rocks older than the Eocene. About twenty feet below the 'Cinder-bed' is a stratum two or three inches thick, in which fossil mammalia presently to be mentioned occur; and beneath this a thin band of greenish shales, with marine shells and impressions of leaves like those of a large *Zostera*, forming the base of the Middle Purbeck.

Fig. 305.



Physa Bristovii, E. Forbes. Middle Purbeck.

Fossil Mammalia of the Middle Purbeck.—In 1852,[1] after

[1] Elements of Geology, 4th edition.

alluding to the discovery of numerous insects and air-breathing mollusca in the Purbeck strata, I remarked that, although no mammalia had then been found, 'it was too soon to infer their non-existence of mere negative evidence.' Only two years after this remark was in print, Mr. W. R. Brodie found in the Middle Purbeck, about twenty feet below the 'Cinder-bed' above alluded to, in Durdlestone Bay, portions of several small jaws with teeth, which Professor Owen recognised as belonging to a small mammifer of the insectivorous class, more closely allied in its dentition to the *Amphitherium* (or *Thylacotherium*) than to any existing type.

Two years later (in 1856) the remains of several other species of warm-blooded quadrupeds were exhumed by Mr. S. H. Beckles, F.R.S., from the same thin bed of marl near the base of the Middle Purbeck. In this marly stratum many reptiles, several insects, and some freshwater shells of the genera *Paludina*, *Planorbis*, and *Cyclas* were found.

Mr. Beckles has thoroughly explored the thin layer of calcareous mud from which in the suburbs of Swanage the bones of the Spalacotherium had already been obtained, and he has brought to light from an area forty feet long and ten wide, and from a layer the average thickness of which was only five inches, portions of the skeletons of six new species of mammalia as interpreted by Dr. Falconer, who first examined them. Before these interesting enquiries were brought to a close, the joint labours of Professor Owen and Dr. Falconer had made it clear that twelve or more species of mammalia characterised this portion of the Middle Purbeck, most of them insectivorous or predaceous, varying in size from that of a mole to that of the common polecat *Mustela putorius*; and Professor Owen has subsequently raised the number of species to twenty-five, referable to ten genera.[2] While the majority had the character of insectivorous marsupials, Dr. Falconer selected one as differing widely from the rest, and pointed out that in certain characters it was allied to the living Kangaroo-rat, or *Hypsiprymnus*, ten species of which now inhabit the prairies and scrub-jungle of Australia, feeding on plants and gnawing scratched-up roots. A striking peculiarity of their dentition, one in which they differ from all other quadrupeds, consists in their having a single large pre-molar, the enamel of which is furrowed with vertical grooves, usually seven in number.

The largest pre-molar (see fig. 307) in the fossil genus exhibits in like manner seven parallel grooves, producing by their termination a similar serrated edge in the crown; but their

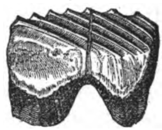
[2] Monograph, Paleontological Society, 1871.

direction is diagonal—a distinction, says Dr. Falconer, which is 'trivial, not typical.' As these oblique furrows form so marked a character of the majority of the teeth, Dr. Falconer gave to

Fig. 306.

Pre-molar of the recent Australian Hypsiprymnus Gaimardi, showing 7 grooves, at right angles to the length of the jaw, magnified 3½ diameters.

Fig. 307.

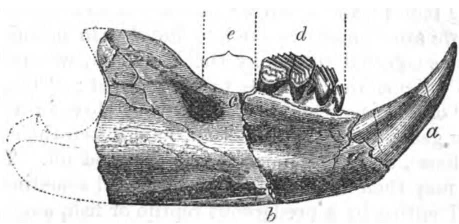


Third and largest pre-molar (lower jaw) of *Plagiaulax Becklesii*, magnified 5½ diameters, showing 7 diagonal grooves.

the fossil the generic name of *Plagiaulax*. The shape and relative size of the incisor *a*, fig. 308, exhibit a no less striking similarity to *Hypsiprymnus*. Nevertheless, the more sudden upward curve of this incisor, as well as other characters of the jaw, indicate a great deviation in the form of *Plagiaulax* from that of the living kangaroo-rats.

There are two fossil specimens of lower jaws of this genus evidently referable to two distinct species extremely unequal in size and otherwise distinguishable. The *Plagiaulax Becklesii* (fig. 308) was about as big as the English squirrel or the flying

Fig. 308.



Plagiaulax Becklesii, Falconer. Middle Purbeck.
Right ramus of lower jaw, magnified two diameters.

a. Incisor. *b, c.* Line of vertical fracture behind the pre-molars. *d.* Three pre-molars, the third and last (much larger than the other two taken together) being divided by a crack. *e.* Sockets of two missing molars.

phalanger of Australia (*Petaurus Australis*, Waterhouse.) The smaller fossil, having only half the linear dimensions of the other, was probably only 1-12th of its bulk. It is of peculiar geological interest, because, as shown by Dr. Falconer, its two back molars bear a decided resemblance to those of the Triassic *Microlestes* (fig. 392, p. 356), the most ancient of known mammalia, of which an account will be given in Chapter XXI.

Up to 1857 all the mammalian remains discovered in secon-

dary rocks had consisted solely of single branches of the lower jaw, but in that year Mr. Beckles obtained the upper portion of a skull and on the same slab the lower jaw of another quadruped with eight molars, a large canine, and a broad and thick incisor. It has been named Triconodon from its three-cone teeth, and is supposed to have been a small insectivorous marsupial, about the size of a hedgehog. Other jaws have since been found indicating a larger species of the same genus.

To the largest of these Professor Owen has given the name of *Triconodon major*. It was a carnivorous mammal, rather larger than the pole-cat, and equalling probably in size the *Dasyurus maugei* of Australia.[3]

Between forty and fifty mandibles or sides of lower jaws with teeth have been found in oolitic strata in Purbeck; only five maxillaries, together with one portion of a separate cranium, occur at Stonesfield, and it is remarkable that with these there were no examples in Purbeck of an entire skeleton, nor of any considerable number of bones in juxtaposition. In several portions of the matrix there were detached bones, often much decomposed, and fragments of others apparently mammalian; but if all of them were restored, they would scarcely suffice to complete the five skeletons to which the five upper maxillaries above alluded to belonged. As the average number of pieces in each mammalian skeleton is about 250, there must be many thousands of missing bones; and when we endeavour to account for their absence, we are almost tempted to indulge in speculations like those once suggested to me by Dr. Buckland, when he tried to solve the enigma in reference to Stonesfield:—'The corpses,' he said, 'of drowned animals, when they float in a river, distended by gases during putrefaction, have often their lower jaw hanging loose, and sometimes it has dropped off. The rest of the body may then be drifted elsewhere, and sometimes may be swallowed entire by a predaceous reptile or fish, such as an ichthyosaur or a shark.'

As all the above-mentioned Purbeck marsupials, belonging to ten genera and to twenty-five species insectivorous, predaceous and herbivorous, have been obtained from an area less than 500 square yards in extent, and from a single stratum not more than a few inches thick, we may safely conclude that the whole lived together in the same region, and in all likelihood they constituted a mere fraction of the mammalia which inhabited the lands drained by one river and its tributaries. They afford the first positive proof as yet obtained of the co-existence of a varied fauna of the highest class of vertebrata with that ample development of reptile life which marks all the periods from the

[3] Owen, Fossil Mammalia of the Purbeck, Paleon. Soc. 1871.

Trias to the Lower Cretaceous inclusive, and with a gymnospermous flora, or that state of the vegetable kingdom when cycads and conifers predominated over all kinds of plants, except the ferns, so far at least as our present imperfect knowledge of fossil botany entitles us to speak.

The annexed table will enable the reader to see at a glance how conspicuous a part, numerically considered, the mammalian species of the Middle Purbeck now play when compared with those of other formations more ancient than the Paris gypsum, and at the same time it will help him to appreciate the enormous hiatus in the history of fossil mammalia which at present occurs between the Eocene and Purbeck periods, and between the latter and the Stonesfield Oolite, and between this again and the Trias.

Number and Distribution of all the known Species of Fossil Mammalia from Strata older than the Paris Gypsum, or than the Bembridge Series of the Isle of Wight (1874.)

TERTIARY.	Headon Series and beds between the Paris Gypsum and the Grès de Beauchamp	14	10 English. 4 French.
	Barton Clay and Sables de Beauchamp . . .	0	
	Bagshot Beds, Calcaire Grossier, and Upper Soissonnais of Cuisse-Lamotte .	20	16 French. 1 English. 3 U. States.[4]
	London Clay, including the Kyson Sand . . .	7 English.	
	Plastic Clay and Lignite .	9	7 French. 2 English.
	Sables de Bracheux . .	1 French.	
	Thanet Sands and Lower Landenian of Belgium .	0	
SECONDARY.	Maestricht Chalk . .	0	
	White Chalk . . .	0	
	Chalk Marl . . .	0	
	Chloritic Series (Upper Greensand) . . .	0	
	Gault	0	
	Neocomian (Lower Greensand)	0	

[4] I allude to several Zeuglodons found in Alabama, and referred by some zoologists to three species.

SECONDARY (*continued*).	Wealden	0	
	Upper Purbeck Oolite	0	
	Middle Purbeck Oolite	25	Swanage.
	Lower Purbeck Oolite	0	
	Portland Oolite	0	
	Kimmeridge Clay	0	
	Coral Rag	0	
	Oxford Clay	0	
	Great Oolite	4	Stonesfield.
	Inferior Oolite	0	
	Lias	0	
	Upper Trias	4	Würtemberg. Somersetsh. N. Carolina.
	Middle Trias	0	
	Lower Trias	0	
PRIMARY.	Permian	0	
	Carboniferous	0	
	Devonian	0	
	Silurian	0	
	Cambrian	0	
	Laurentian	0	

The Sables de Bracheux, enumerated in the Tertiary division of the table, supposed by Mr. Prestwich to be somewhat newer than the Thanet Sands, and by M. Hébert to be of about that age, have yielded at La Fère the *Arctocyon* (*Palæocyon*) *primævus*, the oldest known tertiary mammal.

It is worthy of notice, that in the Hastings Sands there are certain layers of clay and sandstone in which numerous footprints of quadrupeds have been found by Mr. Beckles, and traced by him in the same set of rocks through Sussex and the Isle of Wight. They appear to belong to three or four species of reptiles, and no one of them to any warm-blooded quadruped. They ought, therefore, to serve as a warning to us, when we fail in like manner to detect mammalian footprints in older rocks (such as the New Red Sandstone), to refrain from inferring that quadrupeds, other than reptilian, did not exist or pre-exist.

But the most instructive lesson read to us by the Purbeck strata consists in this :—They are all, with the exception of a few intercalated brackish and marine layers, of freshwater origin ; they are 160 feet in thickness, have been well searched by skilful collectors, and by the late Edward Forbes in particular, who studied them for months consecutively. They have been numbered, and the contents of each stratum recorded separately, by the officers of the Geological Survey of Great Britain.

The stumps of the trees stand erect for a height of from one to three feet, and even in one instance to six feet, with their roots attached to the soil at about the same distances from one another as the trees in a modern forest. The carbonaceous matter is most abundant immediately around the stumps, and round the remains of fossil *Cycadeæ*.

The fragments of the prostrate trees are rarely more than three or four feet in length; but, by joining many of them together, trunks have been restored, having a length from the root to the branches of from 20 to 23 feet, the stems being undivided for 17 or 20 feet, and then forked. The diameter of these near the root is usually about one foot, but I measured one myself in 1866, which was 3½ feet in diameter, said by the quarrymen to be unusually large. Root-shaped cavities were observed by Professor Henslow to descend from the bottom of the dirt-bed

Fig. 309.

Section of Isle of Portland, Dorset. (Buckland and De la Beche.)

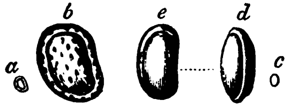
into the subjacent freshwater stone, which, though now solid, must have been in a soft and penetrable state when the trees grew. The thin layers of calcareous shale (fig. 309) were evidently deposited tranquilly, and would have been horizontal but for the protrusion of the stumps of the trees, around the top of each of which they form hemispherical concretions.

They have been divided into three distinct groups by Forbes, each characterised by the same genera of pulmoniferous mollusca and cyprides, these genera being represented in each group by different species; they have yielded insects of many orders, and the fruits of several plants; and lastly, they contain 'dirt-beds,' or old terrestrial surfaces and vegetable soils at different levels, in some of which erect trunks and stumps of cycads and conifers, with their roots still attached to them, are preserved. Yet when the geologist enquires if any land-animals of a higher grade than reptiles lived during any one of these three periods, the rocks are all silent, save one thin layer a few inches in thickness; and this single page of the earth's history has suddenly revealed to us in a few weeks the memorials of so many species of fossil

mammalia, that they already outnumber those of many a subdivision of the tertiary series, and far surpass those of all the other secondary rocks put together!

Lower Purbeck.—Beneath the thin marine band mentioned at p. 311 as the base of the Middle Purbeck some purely freshwater marls occur, containing species of *Cypris* (fig. 310 *a*, *c*), *Valvata*, and *Limnæa*, different from those of the Middle Purbeck. This is the beginning of the inferior division, which is about 80 feet thick. Below the marls are seen, at Meup's Bay, more than 30 feet of brackish-water strata, abounding in a species of *Serpula*, allied to, if not identical with, *Serpula coacervites*, found in beds of the same age in Hanover. There are also shells of the genus *Rissoa* (of the subgenus *Hydrobia*), and a little *Cardium* of the subgenus *Protocardium*, in these marine beds, together with *Cypris*. Some of the cypris-bearing shales are strangely contorted and broken up, at the west end of the Isle of Purbeck. The great dirt-bed or vegetable soil containing the roots and stools of *Cycadeæ*, which I shall presently describe, underlies these marls, and rests upon the lowest freshwater limestone, a rock about eight feet thick, containing *Cyclas*, *Valvata*, and *Limnæa*, of the same species as those of the uppermost part of the Lower Purbeck, or above the dirt-bed. The freshwater limestone in its turn rests upon the top beds of the Portland stone, which, although it contains purely marine remains, often consists of a rock undistinguishable in mineral character from the Lowest Purbeck limestone.

Fig. 310.



Cyprides from the Lower Purbeck.
a. Cypris Purbeckensis, Forbes.
b. Same magnified.
c. Cypris punctata, Forbes.
d, e. Two views magnified of the same.

Dirt-bed or ancient surface soil.—The most remarkable of all the varied succession of beds enumerated in the above list, is that called by the quarrymen 'the dirt,' or 'black dirt,' which was evidently an ancient vegetable soil. It is from 12 to 18 inches thick, is of a dark brown or black colour, and contains a large proportion of earthy lignite. Through it are dispersed rounded and sub-angular fragments of stone, from 3 to 9 inches in diameter, in such numbers that it almost deserves the name of gravel.

Many silicified trunks of coniferous trees, and the remains of plants allied to *Zamia* and *Cycas*, are buried in this dirt-bed, and must have become fossil on the spots where they grew.

I also saw in 1866, in Portland, a smaller dirt-bed six feet below the principal one, six inches thick, consisting of brown

earth with upright *Cycads* of the same species (*Mantellia nidiformis*, fig. 311) as those found in the upper bed, but no *Coniferæ.* The weight of the incumbent strata squeezing down the compressible dirt-bed has caused the *Cycads* to assume that form which has led the quarrymen to call them "petrified birds' nests," which suggested to Brongniart the specific name of *nidiformis.* I am indebted to Mr. Carruthers for the annexed figure of one of these Purbeck specimens, in which the original cylindrical figure has been less distorted than usual by pressure; and I add a figure of the living Cycas that the student may have an idea of a form so predominant in Mesozoic vegetation.

Fig. 311.

Mantellia nidiformis, Brongn.
The upper part shows the woody stem; the lower part the bases of the leaves.

Fig. 312.

Cycas circinalis. Living in the East Indies.[5]

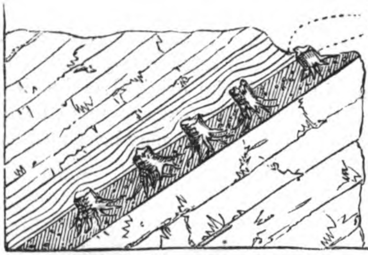
The dirt-bed is by no means confined to the island of Portland, where it has been most carefully studied, but is seen in the same relative position in the cliffs east of Lulworth Cove, in Dorsetshire, where, as the strata have been disturbed, and are now inclined at an angle of 45°, the stumps of the trees are also inclined at the same angle in an opposite direction—a beautiful illustration of a change in the position of beds originally horizontal (see fig. 313).

From the facts above described we may infer, first, that those beds of the Upper Oolite, called 'the Portland,' which are full

[5] Hooker, Descriptive and Analytical Botany, 1873, p. 752

of marine shells, were overspread with fluviatile mud, which became dry land, and covered by a forest, throughout a portion

Fig. 313.



Section of cliff east of Lulworth Cove. (Buckland and De la Beche.)

of the space now occupied by the South of England, the climate being such as to permit the growth of the *Zamia* and *Cycas*. 2ndly. This land at length sank down and was submerged with its forests beneath a body of fresh water, from which sediment was thrown down enveloping fluviatile shells. 3rdly. The regular and uniform preservation of this thin bed of black earth over a distance of many miles, shows that the change from dry land to the state of a freshwater lake or estuary was not accompanied by any violent denudation, or rush of water, since the loose black earth, together with the trees which lay prostrate on its surface, must inevitably have been swept away had any such violent catastrophe taken place.

The forest of the dirt-bed, as before hinted, was not everywhere the first vegetation which grew in this region. Besides the lower bed containing upright *Cycadeæ*, before mentioned, another has sometimes been found above it, which implies oscillations in the level of the same ground, and its alternate occupation by land and water more than once.

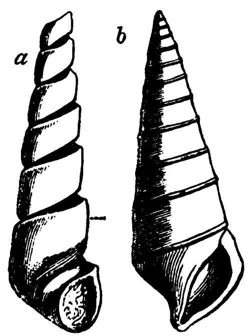
Sub-divisions of the Purbeck.—It will be observed that the division of the Purbecks into upper, middle, and lower, was made by Professor Forbes strictly on the principle of the entire distinctness of the species of organic remains which they include. The lines of demarcation are not lines of disturbance, nor indicated by any striking variations in physical or mineral character. The features which attract the eye in the Purbecks, such as the dirt-beds, the dislocated strata at Lulworth, and the Cinder-bed, do not indicate any breaks in the distribution of organised beings. 'The causes which led to a complete change of life three times during the deposition of the freshwater and brackish strata must,' says this naturalist, 'be sought for, not simply in

either a rapid or a sudden change of their area into land or sea, but in the great lapse of time which intervened between the epochs of deposition at certain periods during their formation.'

Each dirt-bed may, no doubt, be the memorial of many thousand years or centuries, because we find that two or three feet of vegetable soil is the only monument which many a tropical forest has left of its existence ever since the ground on which it now stands was first covered with its shade. Yet, even if we imagine the fossil soils of the Lower Purbeck to represent as many ages, we need not be surprised to find that they do not constitute lines of separation between strata characterised by different zoological types. The preservation of a layer of vegetable soil, when in the act of being submerged, must be regarded as a rare exception to a general rule. It is of so perishable a nature, that it must usually be carried away by the denuding waves or currents of the sea, or by a river; and many Purbeck dirt-beds were probably formed in succession and annihilated, besides those few which now remain.

The plants of the Purbeck beds, so far as our knowledge extends at present, consist chiefly of Ferns, Coniferæ, and Cycadæ (fig. 312), without any angiosperms; the whole more allied to the Oolitic than to the Cretaceous vegetation. The same affinity is indicated by the vertebrate and invertebrate animals. Mr. Brodie has found the remains of beetles and several insects of the homopterous and neuropterous orders, some of which now live on plants, while others are of such forms as hover over the surface of our present rivers.

Fig. 314.



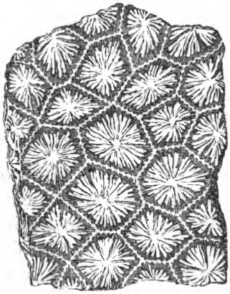
Cerithium Portlandicum (=*Terebra*), Sow., ⅔.

a. Cast of shell known as 'Portland screw.'
b. The shell itself.

Portland Oolite and sand (*b*, Tab., p. 308).—The Portland Oolite has already been mentioned as forming in Dorsetshire the foundation on which the freshwater limestone of the Lower Purbeck reposes (see p. 317). It supplies the well-known building-stone of which St. Paul's and so many of the principal edifices of London are constructed. About fifty species of mollusca occur in this formation, among which are some ammonites of large size. The cast of a spiral univalve called by the quarrymen the 'Portland screw' (*a*, fig. 314), is common; the shell of the same (*b*) being rarely met with. Also *Trigonia gibbosa* (fig. 316) and *Cardium dissimile* (fig. 317). This

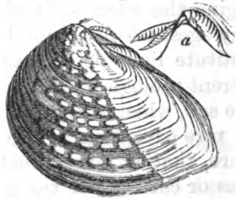
upper member rests on a dense bed of sand, called the Portland sand, containing similar marine fossils, below which is the Kimmeridge clay. In England these Upper Oolite formations are

Fig. 315.



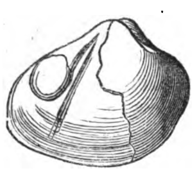
Isastræa oblonga, M. Edw. and J. Haime, mag 2 diams. Converted into chert from the Portland Sand, Tisbury.

Fig. 316.



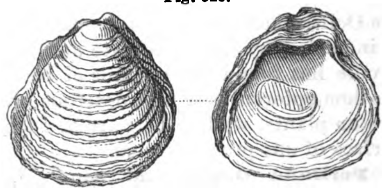
Tigonia gibbosa. ½ nat. size. *a*. The hinge. Portland Stone, Tisbury.

Fig. 317.



Cardium dissimile. ¼ nat. size. Portland Stone.

Fig. 318.



Ostrea expansa. Portland Sand.

almost wholly confined to the southern counties. But some fragments of them occur beneath the Neocomian or Speeton clay on the coast of Yorkshire, containing many more fossils common to the Portlandian of the Continent than does the same formation in Dorsetshire. Corals are rare in this formation, although one species is found plentifully at Tisbury, Wiltshire, in the Portland sand, converted into flint and chert, the original calcareous matter being replaced by silex (fig. 315).

Kimmeridge Clay.—The *Kimmeridge Clay* consists, in great part, of a bituminous shale, sometimes forming an impure coal, several hundred feet in thickness. In some places in Wiltshire it much resembles peat; and the bituminous matter may have been, in part at least, derived from the decomposition of vegetables. But as impressions of plants are rare in these shales,

which contain ammonites, oysters, and other marine shells, with skeletons of fish and saurians, the bitumen may perhaps be of animal origin. Some of the saurians (*Pliosaurus*) in Dorsetshire are among the most gigantic of their kind.

Among the fossils, amounting to nearly 100 species, may be mentioned *Cardium striatulum* (fig. 319) and *Ostrea deltoidea* (fig. 320), the latter found in the Kimmeridge clay throughout

Fig. 319.

Cardium striatulum, ⅔. Kimmeridge Clay, Hartwell.

Fig. 320.

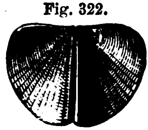
Ostrea deltoidea, Kimmeridge Clay. ¼ nat. size.

Fig. 321.

Gryphæa (*Exogyra*) *virgula*, ⅔. Kimmeridge Clay.

England and the North of France, and also in Scotland, near Brora. The *Gryphæa virgula* (fig. 321), also met with in the Kimmeridge clay near Oxford, is so abundant in the Upper Oolite of parts of France, as to have caused the deposit to be termed 'marnes à gryphées virgules.' Near Clermont, in Argonne, a few leagues from St. Ménehould, where these indurated marls crop out from beneath the gault, I have seen them, on decomposing, leave the surface of every ploughed field literally strewed over with this fossil oyster. The *Trigonellites latus* (*Aptychus*, of some authors) (fig. 322) is also widely dispersed through this clay. The real nature of the shell-like body, of which there are many species in oolitic rocks, is still a matter of conjecture. Some are of opinion that the two plates have been the gizzard of a cephalopod ; others that it may have formed a bivalve operculum of the same.

Fig. 322.

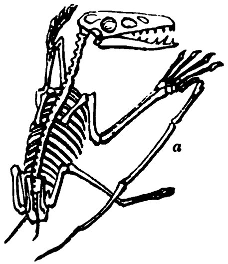


Trigonellites latus, Park, Kimmeridge Clay.

Solenhofen Stone.—The celebrated lithographic stone of Solenhofen, in Bavaria, appears to be of intermediate age between the Kimmeridge Clay and the Coral Rag, presently to be described. It affords a remarkable example of the variety of fossils which may be preserved under favourable circumstances, and what delicate impressions of the tender parts of certain animals and plants may be retained where the sediment is of extreme fineness. Although the number of testacea in

this slate is small, and the plants few, and those all marine, Count Münster had determined no less than 237 species of fossils when I saw his collection in 1833; and among them no less than seven *species* of flying reptiles or pterodactyls (see fig. 323), six saurians, three tortoises, sixty species of fish, forty-six of crustacea, and twenty-six of insects. These insects, among which is a libellula, or dragon-fly, must have been blown out to sea, probably from the same land to which the Pterodactyls, and other contemporaneous air breathers, resorted.

Fig. 323.



Skeleton of *Pterodactylus crassirostris*.
Oolite of Pappenheim, near Solenhofen.

The bone *a*, consisting of four joints, is part of the fifth or outermost digit elongated, for the support of a wing.

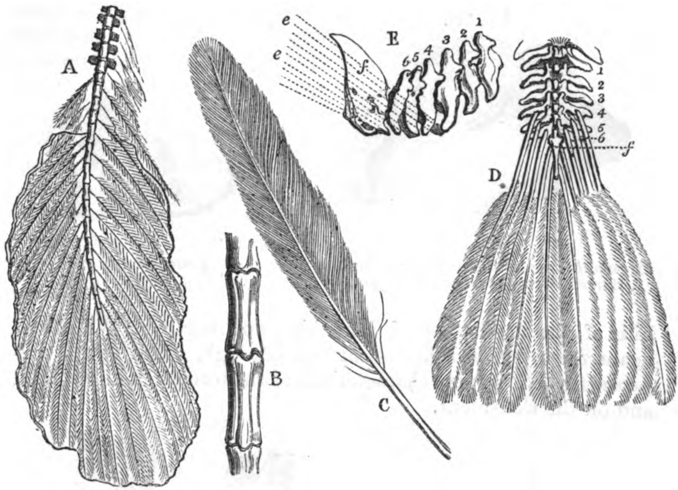
In the same slate of Solenhofen a fine example was met with in 1862 of the skeleton of a bird almost entire, and retaining even its feathers so perfect that the vanes as well as the shaft are preserved. It has been called by Professor Owen *Archæopteryx macrura*. Although anatomists agree that it is a true bird, yet they also find that in the length of the bones of the tail, and some other minor points of its anatomy, it approaches more nearly to reptiles than any known living bird. In the living representatives of the class Aves, the tail feathers are attached to a coccygian bone, consisting of several vertebræ united together; whereas in the Archæopteryx the tail is composed of twenty vertebræ, each of which supports a pair of quill feathers.

Professor Huxley, in his late memoir on the order of reptiles called Dinosaurians, which are largely represented in all the formations, from the Neocomian to the Trias inclusive, has shown that they present in their structure many remarkable affinities to birds. But a reptile about two feet long, called Compsognathus, lately found in the Stonesfield slate, makes a much greater approximation to the class Aves than any Dinosaur, and therefore forms a closer link between the classes Aves and Reptilia than does the Archæopteryx.

It appears doubtful whether any species of British fossil, whether of the vertebrate or invertebrate class, is common to the Oolite and Chalk. But there is no similar break or discordance as we proceed downwards, and pass from one to another of the several leading members of the Jurassic group, the Upper, Middle, and Lower Oolite, and the Lias, there being often a considerable proportion of the mollusca, sometimes as much as

a fourth, common to such divisions as the Upper and Middle Oolite.

Fig. 324.



Tail and feather of *Archæopteryx*, from Solenhofen, and tail of living bird for comparison.

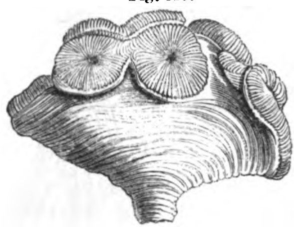
A. Caudal vertebræ of *Archæopteryx macrura*, Owen; with impression of tail feathers, ⅛ nat. size.
B. Two caudal vertebræ of same, nat. size.
C. Single feather, found in 1861 at Solenhofen, by Von Meyer, and called *Archæopteryx lithographica*. Nat. size.
D. Tail of recent vulture (*Gyps Bengalensis*), showing attachment of tail-feathers in living birds. ⅛ nat. size.
E. Profile of caudal vertebræ of same, ⅛ nat. size. *e, e.* Direction of tail-feathers when seen in profile. *f.* Ploughshare bone or broad terminal joint (seen also in *f*, D.)

MIDDLE OOLITE.

Coral Rag.—One of the limestones of the Middle Oolite has been called the 'Coral Rag,' because it consists, in part, of continuous beds of petrified corals, most of them retaining the position in which they grew at the bottom of the sea. In their forms they more frequently resemble the reef-building polyparia of the Pacific than do the corals of any other member of the Oolite. They belong chiefly to the genera *Thecosmilia* (fig. 325), *Protoseris*, and *Thamnastræa*, and sometimes form masses of coral fifteen feet thick. In the annexed figure of a *Thamnastræa* (fig. 326), from this formation, it will be seen that the cup-shaped cavities are deepest on the right-hand side, and that they grow more and more shallow, until those on the left side

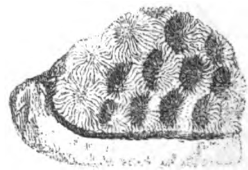
are nearly filled up. The last-mentioned stars are supposed to represent a perfected condition, and the others an immature state. These coralline strata extend through the calcareous

Fig. 325.



Thecosmilia annularis, Milne Edw., ½; and J. Haime. Coral Rag, Steeple Ashton.

Fig. 326.



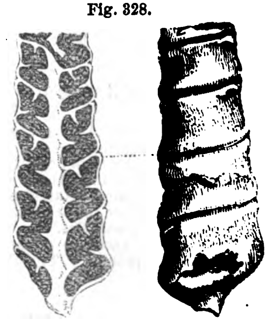
Thamnastræa, Coral Rag, Steeple Ashton.

hills of the north-west of Berkshire, and north of Wilts, and again recur in Yorkshire, near Scarborough. The *Ostrea gregarea* (fig. 327) is very characteristic of the formation in England and on the Continent.

Fig. 327.

Ostrea gregarea, ⅓. Coral Rag, Steeple Ashton.

Fig. 328.



Nerinæa Goodhallii. Coral Rag, Weymouth. ¼ nat. size.

One of the limestones of the Jura, referred to the age of the English coral rag, has been called 'Nerinæan limestone' (Calcaire à Nérinées) by M. Thirria; *Nerinæa* being an extinct genus of univalve shells (fig. 328) much resembling *Cerithium* in external form. The annexed section shows the curious and continuous ridges on the columella and whorls.

Oxford Clay.—The coralline limestone, or 'coral rag,' above described, and the accompanying sandy beds, called 'calcareous grits,' of the Middle Oolite, rest on a thick bed of clay, called the 'Oxford Clay,' sometimes not less than 600 feet thick. In

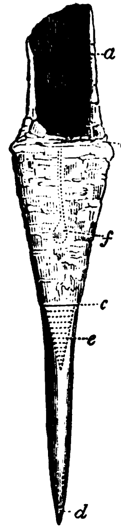
this there are no corals, but great abundance of cephalopoda, of the genera Ammonite and Belemnite. In some of the finely laminated clays ammonites are very perfect, although somewhat compressed, and are frequently found with the lateral lobe extended on each side of the aperture into a horn-like projection (see fig. 330). These were discovered in the cuttings of the Great Western Railway, near Chippenham, in 1841, and have been described by Mr. Pratt (*An. Nat. Hist.*, Nov. 1841).

Similar elongated processes have been also observed to extend from the phragmacone of some belemnites discovered by Dr. Mantell in the same clay (see fig. 331), who, by the aid

Fig. 329.

Belemnites hastatus, ⅓. Oxford Clay.

Fig. 331.



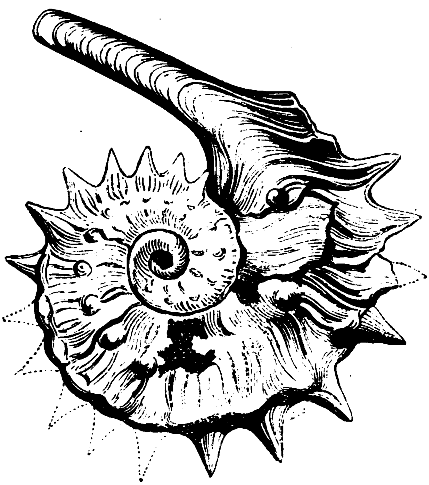
Belemnites Puzosianus, d'Orb.

B. Owenii, Pierce, ⅙.

Oxford Clay, Christian Malford.

a. Section of the shell projecting from the phragmacone.
b–c. External covering to the ink-bag and phragmacone.
c, *d*. Osselet, or that portion commonly called the belemnite.
e. Conical chambered body called the phragmacone.
f. Position of ink-bag beneath the shelly covering.

Fig. 330.



Ammonites, Jason, Reincke. (Syn. *A. Elizabethæ*, Pratt.) Oxford Clay, Christian Malford, Wiltshire.

of this and other specimens, has been able to throw much light on the structure of singular extinct forms of cuttle fish.[6]

[6] See Phil. Trans. 1850, p. 363; also Huxley, Memoirs of Geol. Survey 1864; Phillips, Paleont. Soc.

Kelloway Rock.—The arenaceous limestone which passes under this name is generally grouped as a member of the Oxford clay, in which it forms, in the south-west of England, lenticular masses, 8 or 10 feet thick, containing at Kelloway, in Wiltshire, numerous casts of ammonites, and other shells. But in Yorkshire this calcareo-arenaceous formation thickens to about 30 feet, and constitutes the lower part of the Middle Oolite, extending inland from Scarborough in a southerly direction. The number of mollusca which it contains is, according to Mr. Etheridge, 143, of which only 34, or 23½ per cent., are common to the Oxford clay proper. Of the 52 Cephalopoda, fifteen (namely, 13 species of ammonite, the *Ancyloceras Calloviense* and one Belemnite) are common to the Oxford clay, giving a proportion of nearly 30 per cent.

LOWER OOLITE.

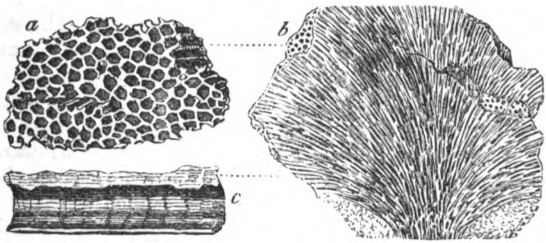
Cornbrash and Forest Marble.—The upper division of this series, which is more extensive than the preceding or Middle Oolite, is called in England the Cornbrash, as being a brashy, easily broken rock, good for corn land. It consists of clays and calcareous sandstones, which pass downwards into the Forest Marble, an argillaceous limestone, abounding in marine fossils. In some places, as at Bradford, near Bath, this limestone is replaced by a mass of clay. The sandstones of the Forest Marble of Wiltshire are often ripple-marked and filled with fragments of broken shells and pieces of drift-wood, having evidently been formed on a coast. Rippled slabs of fissile oolite are used for roofing, and have been traced over a broad band of country from Bradford in Wilts, to Tetbury in Gloucestershire. These calcareous tile-stones are separated from each other by thin seams of clay, which have been deposited upon them, and have taken their form, preserving the undulating ridges and furrows of the sand in such complete integrity, that the impressions of small footsteps, apparently of crustaceans, which walked over the soft, wet sands, are still visible. In the same stone the claws of crabs, fragments of echini, and other signs of a neighbouring beach, are still observed.[7]

Great (or Bath) Oolite.—Although the name of coral rag has been appropriated, as we have seen, to the highest member of the Middle Oolite before described, some portions of the Lower Oolite are equally entitled in many places to be called coralline limestones. Thus the Great Oolite near Bath contains

[7] P. Scrope, Proc. Geol. Soc. March 1831.

various corals, among which the *Eunomia radiata* (fig. 332) is very conspicuous, single individuals forming masses several feet in diameter ; and having probably required, like the large exist-

Fig. 332.



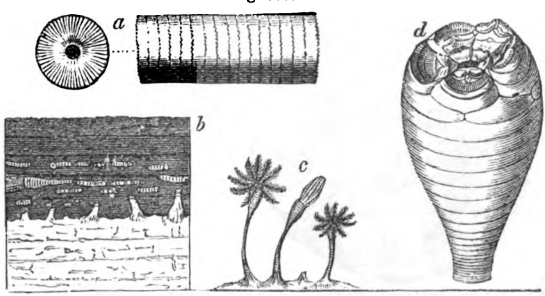
Eunomia radiata, Lamouroux. (*Calamophyllia*, Milne Edw.)

a. Section transverse to the tubes.
b. Vertical section, showing the radiation of the tubes.
c. Portion of interior of tubes magnified, showing striated surface.

ing brain coral (*Meandrina*) of the tropics, many centuries before their growth was completed.

Different species of crinoids, or stone-lilies, are also common in the same rocks with corals ; and, like them, must have lived on a firm bottom, where their base of attachment remained un-

Fig. 333.



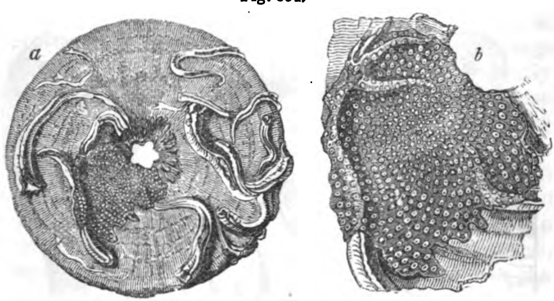
Apiocrinites rotundus, or Pear Encrinite ; Miller. Fossil at Bradford, Wilts.

a. Stem of *Apiocrinites*, and one of the articulations, natural size.
b. Section at Bradford of Great Oolite and overlying clay, containing the fossil encrinites.
c. Three perfect individuals of *Apiocrinites*, represented as they grew on the surface of the Great Oolite.
d. Body of the *Apiocrinites rotundus*. Half nat. size.

disturbed for years (*c*, fig. 333). Such fossils, therefore, are almost confined to the limestones ; but an exception occurs at Bradford, near Bath, where they are enveloped in clay some-

times 60 feet thick. In this case, however, it appears that the solid upper surface of the 'Great Oolite' had supported, for a time, a thick submarine forest of these beautiful crinoids, until the clear and still water was invaded by a current charged with mud, which threw down the stone-lilies, and broke most of their stems short off near the point of attachment. The stumps still remain in their original position; but the numerous articulations, once composing the stem, arms, and body of the encrinite, were scattered at random through the argillaceous deposit in which some now lie prostrate. These appearances are represented in the section *b*, fig. 333, where the darker strata represent the Bradford clay, which is, however, a formation of such local development that in many places it cannot be easily separated from the clays of the overlying 'forest-marble' and underlying 'fuller's earth.' The upper surface of the calcareous stone below is completely incrusted over with a continuous pavement, formed by the stony roots or attachments of the Crinoidea; and, besides this evidence of the length of time they had lived on the spot, we find great numbers of single joints, or circular plates of the stem and body of the encrinite, covered over with *serpulæ*. Now these *serpulæ* could only have begun to grow after the death of some of the stone-lilies, parts of whose skeletons had been strewed over the floor of the ocean

Fig. 334.



a. Single plate of body of *Apiocrinus*, overgrown with *serpulæ* and *polyzoa*. Natura size. Bradford Clay.
b. Portion of the same magnified, showing the polyzoan *Diastopora diluviana* covering one of the *serpulæ*.

before the irruption of argillaceous mud. In some instances we find that, after the parasitic *serpulæ* were full grown, they had become incrusted over with a polyzoan, called *Diastopora diluviana* (see *b*, fig. 334); and many generations of these molluscoids had succeeded each other in the pure water before they became fossil.

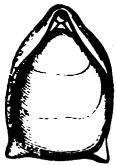
We may, therefore, perceive distinctly that, as the pines and cycadeous plants of the ancient 'dirt-bed,' or fossil forest, of the Lower Purbeck were killed by submergence under fresh water, and soon buried beneath muddy sediment, so an invasion of argillaceous matter put a sudden stop to the growth of the Bradford Encrinites, and led to their preservation in marine strata.

Such differences in the fossils as distinguish the calcareous and argillaceous deposits from each other, would be described by naturalists as arising out of a difference in the *stations* of species; but besides these, there are variations in the fossils of the higher, middle, and lower part of the oolitic series, which must be ascribed to that great law of change in organic life by which distinct assemblages of species have been adapted, at successive geological periods, to the varying conditions of the habitable surface. In a single district it is difficult to decide how far the limitation of species to certain minor formations has been due to the local influence of *stations*, or how far it has been caused by time or the law of variation above alluded to. But we recognise the reality of the last-mentioned influence, when we contrast the whole oolitic series of England with that of parts of the Jura, Alps, and other distant regions, where, although there is scarcely any lithological resemblance, yet some of the same fossils remain peculiar in each country to the Upper, Middle, and Lower Oolite formations respectively. Mr. Thurmann has shown how remarkably this fact holds true in the Bernese Jura, although the argillaceous divisions, so conspicuous in England, are feebly represented there, and some entirely wanting.

The calcareous portion of the Great Oolite consists of several shelly limestones, one of which, called the Bath Oolite, is much celebrated as a building-stone. In parts of Gloucestershire, especially near Minchinhampton, the Great Oolite, says Mr. Lycett, 'must have been deposited in a shallow sea, where strong currents prevailed, for there are frequent changes in the mineral character of the deposit, and some beds exhibit false stratification. In others, heaps of broken shells are mingled with pebbles of rocks foreign to the neighbourhood, and with fragments of abraded madrepores, dicotyledonous wood, and crabs' claws. The shelly strata, also, have occasionally suffered denudation, and the removed portions have been replaced by clay.' In such shallow-water beds shells of the genera *Patella*, *Nerita*, *Rimula*, and *Cylindrites* are common (see figs. 337 to 340); while cephalopods are rare, and, instead of ammonites and belemnites, numerous genera of carnivorous trachelipods appear.

Out of 224 species of univalves obtained from the Minchinhampton beds, Mr. Lycett found no less than 50 to be carnivorous.

Fig. 335.

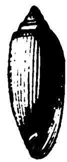


Terebratula digona, Sow., nat. size. Bradford Clay.

Fig. 336

Pupuroidea nodulata, ½ nat. size. Great Oolite, Minchinhampton.

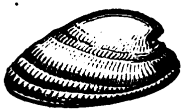
Fig. 337



Cylindrites acutus, Sow Syn. *Actæon acutus*, nat. size. Great Oolite, Minchinhampton.

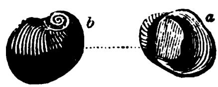
They belong principally to the genera *Buccinum*, *Pleurotoma*, *Rostellaria*, *Murex*, *Purpuroidea* (fig. 336), and *Fusus*, and exhibit a proportion of zoophagous species not very different from

Fig. 338.



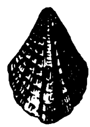
Patella rugosa, Sow., ⅜. Great Oolite.

Fig. 339.



Nerita costulata, Desh., mag. 2 diams. Great Oolite.

Fig. 340.



Rimula (*Emarginula*) *clathrata*, Sow., mag. 3 diams. Great Oolite.

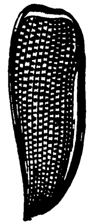
that which obtains in seas of the Recent period. These zoological results are curious and unexpected, since it was imagined that we might look in vain for the carnivorous trachelipods in rocks of such high antiquity as the Great Oolite, and it was a received doctrine that they did not begin to appear in considerable numbers till the Eocene period, when those two great families of cephalopoda, the Ammonites and Belemnites, and a great number of other representatives of the same class of chambered shells, had become extinct.

Stonesfield Slate: Mammalia.—The slate of Stonesfield has been shown by Mr. Lonsdale to lie at the base of the Great Oolite.[8] It is a slightly oolitic shelly limestone, forming large lenticular masses embedded in sand, only 6 feet thick, but very rich in organic remains. It contains some pebbles of a rock very similar to itself, and which may be portions of the deposit, broken up on a shore at low water or during storms, and redeposited. The remains of belemnites, trigoniæ, and other

8 Proceedings Geol. Soc., vol. i. p. 414.

marine shells, with fragments of wood, are common, and impressions of ferns, cycadeæ, and other plants. Several insects, also, and, among the rest, the elytra or wing-covers of beetles, are perfectly preserved (see fig. 341), some of them approaching nearly to the genus *Buprestis.* The remains, also, of many genera of reptiles, such as *Pleiosaur*, *Crocodile*, and *Pterodactyl*, have been discovered in the same limestone.

Fig. 341.



Elytron of *Buprestis?* nat. size. Stonesfield.

But the remarkable fossils for which the Stonesfield slate is most celebrated are those referred to the mammiferous class. The student should be reminded that in all the rocks described in the preceding chapters as older than the Eocene, no bones of any land-quadruped, or of any cetacean, had been discovered until the *Spalacotherium* of the Purbeck beds came to light in 1854. Yet we have seen that terrestrial plants were not wanting in the Upper Cretaceous formation (see p. 285), and that in the Wealden there was evidence of freshwater sediment on a large scale, containing various plants, and even ancient vegetable soils. We had also in the same Wealden many land-reptiles and winged insects, which render the absence of terrestrial quadrupeds the more striking. The want, however, of any bones of whales, seals, dolphins, and other aquatic mammalia, whether in the chalk or in the Upper or Middle Oolite, is certainly still more remarkable.

These observations are made to prepare the reader to appreciate more justly the interest felt by every geologist in the discovery in the Stonesfield slate (see Table, p. 315) of no less than ten specimens of lower jaws of mammiferous quadrupeds, belonging to four different species and to three distinct genera, for which the names of *Amphitherium*, *Phascolotherium*, and *Stereognathus* have been adopted.

It is now generally admitted that these are really the remains

Fig. 342.

Tupaia Tana.
Right ramus of lower jaw.
Natural size.
A recent insectivorous placental mammal, from Sumatra.

of mammalia (although it was at first suggested that they might be reptiles), and the only question open to controversy is limited to this point, whether the fossil mammalia found in the Lower Oolite of Oxfordshire ought to be referred to the marsupial quadrupeds, or to the ordinary placental series. Cuvier had

long ago pointed out a peculiarity in the form of the angular process (*c*, figs. 345 and 346) of the lower jaw, as a character of the genus *Didelphys*; and Professor Owen has since confirmed the doctrine of its generality in the entire marsupial series. In all these pouched quadrupeds this process is turned inwards, as at *c*, *d*, fig. 345, in the Brazilian opossum, whereas in the placental series, as at *c*, figs. 343 and 344, there is an almost entire

Fig. 343.

Fig. 344.

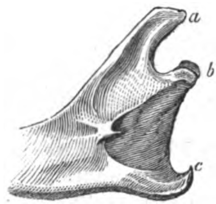


Fig. 345.

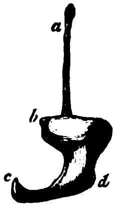


Fig. 346.

Part of lower jaw of *Tupaia Tana*.
Twice natural size.

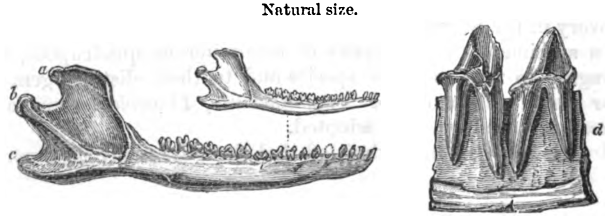
Fig. 343. End view seen from behind, showing the very slight inflection of the angle at *c*.
Fig. 344. Side view of same.

Part of lower jaw of *Didelphys Azaræ*; recent, Brazil. Natural size.

Fig. 345. End view seen from behind, showing the inflection of the angle of the jaw, *c*, *d*.
Fig. 346. Side view of same.

absence of such inflection. The *Tupaia Tana* of Sumatra has been selected by Mr. Waterhouse for this illustration, because the jaws of that small insectivorous quadruped bear a great resemblance to those of the Stonesfield *Amphitherium*. By clearing away the matrix from the specimen of *Amphitherium*

Fig. 347.
Natural size.



Amphytherium Prevostii, Cuv. sp. Stonesfield Slate.
Syn. *Thylacotherium Prevostii*, Valenc.
a. Coronoid process. *b*. Condyle. *c*. Angle of jaw. *d*. Double-fanged molars.

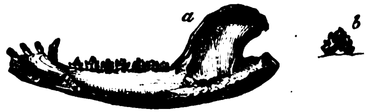
Prevostii here represented (fig. 347), Professor Owen ascertained that the angular process (*c*) bent inwards in a slighter degree than in any of the known marsupialia; in short, the inflection does not exceed that of the mole or hedgehog. This fact made him doubt whether the *Amphitherium* might not be an insectivorous placental, although it offered some points of ap-

proximation in its osteology to the marsupials, especially to the *Myrmecobius*, a small insectivorous quadruped of Australia which has nine molars on each side of the lower jaw, besides a canine and three incisors.[9] Another species of *Amphitherium* has been found at Stonesfield (fig. 348), which differs from the former (fig. 347) principally in being larger.

Fig. 348.

Amphitherium Broderipii, Owen. Natural size. Stonesfield Slate.

Fig. 349.



Phascolotherium Bucklandi, Broderip, sp. *a.* Natural size. *b.* Molar of same, magnified.

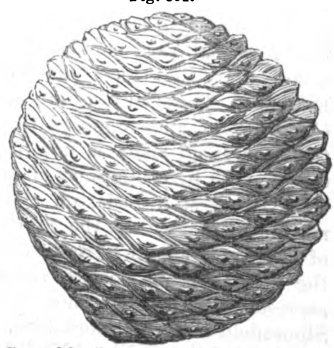
The second mammiferous genus discovered in the same slates was named originally by Mr. Broderip *Didelphys Bucklandi* (see fig. 349), and has since been called *Phascolotherium* by Owen. It manifests a much stronger likeness to the marsupials in the general form of the jaw, and in the extent and position of its inflected angle, while the agreement with the living genus *Didelphys* in the number of the pre-molar and molar teeth is complete.[1]

In 1854 the remains of another mammifer, small in size, but larger than any of those previously known, was brought to

Fig. 350.

Portion of a fossil fruit of *Podocarya Bucklandi*, Ung., magnified. (Buckland's Bridgw. Treatise. Pl. 63.) Inferior Oolite, Charmouth, Dorset.

Fig. 351.



Cone of fossil *Araucaria Sphærocarpa*, Carr. Inferior Oolite. Bruton, Somersetshire. $\frac{1}{3}$ diameter of original. In the collection of the British Museum.

light. The generic name of *Stereognathus* was given to it, and as is usually the case in these old rocks (see above, p. 314), it

[9] A figure of this recent *Myrmecobius* will be found in my Principles of Geology, chap. ix.

[1] Owen's British Fossil Mammals, p. 62.

consisted of part of a lower jaw, in which were implanted three double-fanged teeth, differing in structure from those of all other known recent or extinct mammals.

Plants of the Oolite.—The Araucarian pines, which are now abundant in Australia and its islands, together with marsupial quadrupeds, are found in like manner to have accompanied the marsupials in Europe during the Oolitic period (see fig. 351). In the same rock endogens of the most perfect structure are met with, as, for example, fruits allied to the Pandanus, such as the *Kaidacarpum ooliticum* of Carruthers in the Great Oolite and the *Podocarya* of Buckland (see fig. 350) in the Inferior Oolite.

Fuller's Earth.—Between the Great and Inferior Oolite in the West of England, an argillaceous deposit, called 'the fuller's earth,' occurs; but it is wanting in the North of England. It abounds in the small oyster represented in fig. 352. The number of mollusca known in this deposit is about seventy; namely, fifty Lamellibranchiate Bivalves, ten Brachiopods, three Gasteropods, and seven or eight Cephalopods.

Fig. 352.

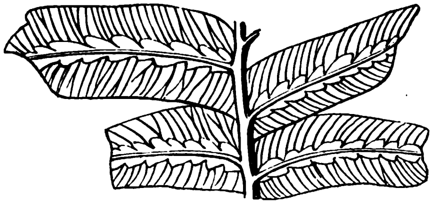
Ostrea acuminata.
Fuller's Earth.

Inferior Oolite.—This formation consists of a calcareous freestone, usually of small thickness, but attaining in some places, as in the typical area of Cheltenham and the Western Cotswolds, a thickness of 250 feet. It sometimes rests upon yellow sands, formerly classed as the sands of the Inferior Oolite, but now regarded as a member of the Upper Lias. These sands repose upon the Upper Lias clays in the South and West of England. The Collyweston slate, formerly classed with the Great Oolite, and supposed to represent in Northamptonshire the Stonesfield slate, is now found to belong to the Inferior Oolite, both by community of species and position in the series. The Collyweston beds, on the whole, assume a much more marine character than the Stonesfield slate. Nevertheless, one of the fossil plants (*Aroides Stutterdi*, Carr.), remarkable, like the Pandanaceous species before mentioned (fig. 350), as a representative of the monocotyledonous class, is common to the Stonesfield beds in Oxfordshire.

The Inferior Oolite of Yorkshire consists largely of shales and sandstones, which assume much the aspect of a true coal-field, thin seams of coal having actually been worked in them for more than a century. A rich harvest of fossil ferns has been obtained from them, as at Gristhorpe, near Scarborough (fig. 353). They contain also Cycadæ, of which family a magnificent specimen has been described by Mr. Williamson under the name Zamia Gigas, and a fossil called *Equisetum Columnare* (see fig.

400, p. 365), which maintains an upright position in sandstone strata over a wide area. Shells of *Esthéria* and *Unio*, collected

Fig. 353.

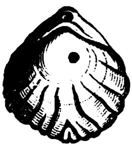


Hemitelites Brownii, Goepp. Syn. *Phlebopteris contigua*, Lind. and Hutt. Lower carbonaceous strata, Inferior Oolite shales. Gristhorpe, Yorkshire.

by Mr. Bean from these Yorkshire coal-bearing beds, point to the estuary or fluviatile origin of the deposit.

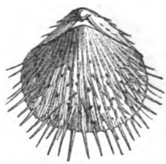
At Brora, in Sutherlandshire, a coal seam probably coeval with the above,[2] or at least older than the Kelloway Rock, the

Fig. 354.



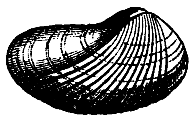
Terebratula fimbria, Sow., $\frac{1}{2}$. Inferior Oolite marl. Cotswold Hills.

Fig. 355.



Rhynchonella spinosa, Schloth, $\frac{2}{3}$. Inferior Oolite.

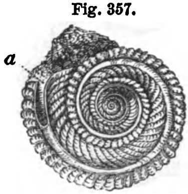
Fig. 356.



Pholadomya fidicula, Sow., $\frac{1}{3}$ natural size. Inferior Oolite.

lowest marine bed of the middle Oolitic period, was extensively mined nearly a century ago. It affords the thickest stratum of pure vegetable matter hitherto detected in any secondary rock

Fig. 357.

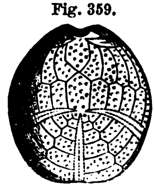


Pleurotomaria granulata, Sow., $\frac{1}{2}$. Ferruginous Ool., Normandy. Inferior Oolite, England. Under side.

Fig. 358.

Pleurotomaria ornata, Sow. Sp. Inferior Oolite. $\frac{1}{3}$ nat. size.

Fig. 359.



Collyrites (*Dysaster*) *ringens*, Agass. Inf. Ool., Somersetshire.

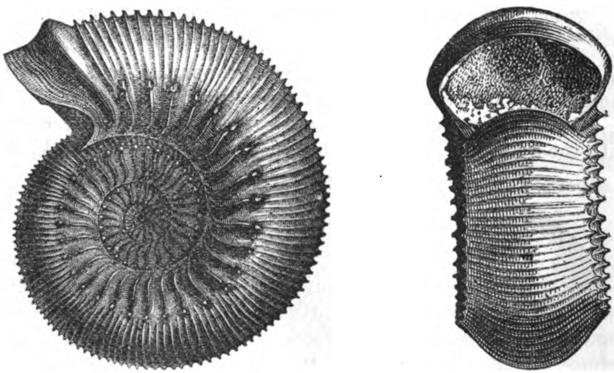
in England, upwards of 80,000 tons having been extracted. One

[2] See Judd, Quart. Geol. Journ., vol. xxix. p. 164.

seam of coal of good quality, $3\frac{1}{2}$ feet thick, is now being worked, and there is pyritous coal resting upon it. The roof-bed of the coal is literally composed of marine shells, such as *Pholadomya*, *Trigonia*, *Goniomya*, *Pteroperna*, *Cerithium*, &c.

Among the characteristic shells of the Inferior Oolite, I may instance *Terebratula fimbria* (fig. 354), *Rhynchonella spinosa* (fig. 355), and *Pholadomya fidicula* (fig. 356). The extinct genus *Pleurotomaria* is also a form very common in this division as well as in the Oolitic system generally. It resembles *Trochus* in form, but is marked by a deep cleft (*a*, figs. 357, 358) on one

Fig. 360.



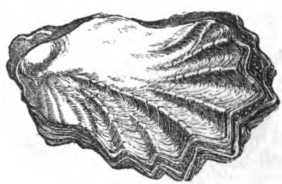
Ammonites Humphresianus, Sow., $\frac{1}{2}$. Inferior Oolite.

side of the aperture. The *Collyrites* (*Dysaster*) *ringens* (fig. 359) is an Echinoderm common to the Inferior Oolite of England and France, as are the two Ammonites (figs. 360, 361).

Fig. 361.

Ammonites Braikenridgii, Sow., $\frac{1}{8}$.
Oolite, Scarborough.
Inf. Ool., Dundry; Calvados, &c.

Fig. 362.



Ostrea Marshii. $\frac{1}{2}$ natural size.
Middle and Lower Oolite.

Palæontological relations of the Oolitic strata.—Observations have already been made (p. 324) on the distinctness of the organic remains of the Oolitic and Cretaceous strata, and

the proportion of species common to the different members of the Oolite. Between the Lower Oolite and the Lias there is a somewhat greater break, for out of 256 mollusca of the Upper Lias, thirty-seven species only pass up into the Inferior Oolite.

In illustration of shells having a great vertical range, it may be stated that in England some few species pass up from the Lower to the Upper Oolite, as, for example, *Rhynchonella obsoleta*, *Lithodomus inclusus*, *Pholadomya ovalis*, and *Trigonia costata*.

Fig. 363.

Ammonites macrocephalus, Schloth. ⅓ nat. size. Great Oolite and Oxford Clay.

Of all the Jurassic Ammonites of Great Britain, *A. macrocephalus* (fig. 363), which is common to the Great Oolite and Oxford Clay, has the widest range.

We have every reason to conclude that the gaps which occur, both between the larger and smaller sections of the English Oolites, imply intervals of time elsewhere represented by fossiliferous strata, although no deposit may have taken place in the British area. This conclusion is warranted by the partial extent of many of the minor and some of the larger divisions even in England.

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CHAPTER XXI.

TRIAS, OR NEW RED SANDSTONE GROUP.

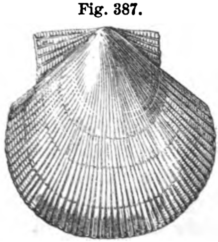
Beds of passage between the Lias and Trias, Rhætic beds—Triassic mammifer—Triple division of the Trias Keuper, or Upper Trias of England—Reptiles of the Upper Trias—Footprints in the Bunter formation in England—Dolomitic conglomerate of Bristol—Origin of Red Sandstone and Rock-salt—Precipitation of salt from inland lakes and lagoons—Trias of Germany—Keuper—St. Cassian and Hallstadt beds—Peculiarity of their fauna—Muschelkalk and its fossils—Trias of the United States—Fossil footprints of birds and reptiles in the valley of the Connecticut—Triassic mammifer of North Carolina—Triassic coal-field of Richmond, Virginia—Low grade of early mammals favourable to the theory of progressive development.

Beds of passage between the Lias and Trias—Rhætic beds.—We have mentioned in the last chapter (p. 343) that the base of the Lower Lias is characterised, both in England and Germany, by beds containing distinct species of Ammonites, the lowest subdivision having been called the zone of *Ammonites Planorbis*. Below this zone, on the boundary line between the Lias and the strata of which we are about to treat, called 'Trias,' certain cream-coloured limestones are usually found in the West and South of England. These white beds were called by William Smith the White Lias, and they have been shown by Mr. Charles Moore to belong to a formation similar to one in the Rhætian Alps of Bavaria, to which M. Gümbel has applied the name of

Fig. 386.

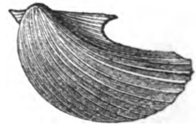
Cardium rhæticum, Merian. Nat. size. Rhætic Beds.

Fig. 387.



Pecten Valoniensis, Dfr. ½ nat. size. Portrush, Ireland, &c. Rhætic Beds.

Fig. 388.



Avicula contorta, Portlock. Portrush, Ireland, &c. Nat. size. Rhætic Beds.

Rhætic. They have also long been known as the Koessen beds in Germany, and may be regarded as beds of passage between

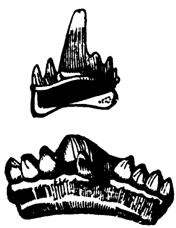
the Lias and Trias. They are named the Penarth beds by the Government surveyors of Great Britain, from Penarth, near Cardiff, in Glamorganshire, where they attain a thickness of fifty feet.

The principal member of this group has been called by Dr. Wright the *Avicula contorta* bed,[1] as this shell is very abundant, and has a wide range in Europe. General Portlock first described the formation as it occurs at Stradneagh, near Portrush, in Antrim, where the *Avicula contorta* (fig. 388) is accompanied by *Pecten Valoniensis* (fig. 387) as in Germany.

The best known member of the group, a thin band or bone-breccia, is conspicuous among the black shales in the neighbourhood of Axmouth in Devonshire, and in the cliffs of Westbury-on-Severn, as well as at Aust and other places on the borders of the Bristol Channel. It abounds in the remains of saurians and fish, and was formerly classed as the lowest bed of the Lias; but Sir P. Egerton first pointed out, in 1841, that it should be referred to the Upper New Red Sandstone, because it contained an assemblage of fossil fish which are either peculiar to this stratum or belong to species well known in the Muschelkalk of Germany. These fish belong to the genera *Acrodus*, *Hybodus*, *Gyrolepis*, and *Saurichthys*.

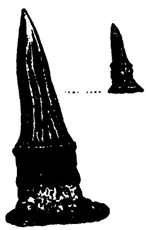
Among those common to the English bone-bed and the Muschelkalk of Germany are *Hybodus plicatilis* (fig. 389), *Saurichthys*

Fig. 389.



Hybodus plicatilis, Agass. Teeth, Bone-bed, Aust and Axmouth.

Fig. 390.



Saurichthys apicalis, Agass. Tooth; natural size and magnified. Axmouth.

Fig. 391.

Gyrolepis tenuistriatus, Agass. Scale: nat. size and magnified. Axmouth.

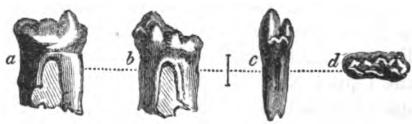
apicalis (fig. 390), *Gyrolepis tenuistriatus* (fig. 391), and *G. Albertii*. Remains of saurians, *Plesiosaurus* among others, have also been found in the bone-bed, and plates of an *Encrinus*. It may be questioned whether some of those fossils which have the most Triassic character may not have been derived from the

[1] Dr. Wright, on Lias and Bone Bed, Quart. Geol. Journ. 1860, vol. xvi.

destruction of older strata, since in bone beds, in general, many of the organic remains are undoubtedly derivative.

Triassic mammifer.—In North-western Germany, as in England, there occurs beneath the Lias a remarkable bone breccia. It is filled with shells and with the remains of fishes and reptiles, almost all the genera of which, and some even of the species, agree with those of the subjacent Trias. This breccia has accordingly been considered by Professor Quenstedt and other German geologists of high authority, as the newest or uppermost part of the Trias. Professor Plieninger found in it, in 1847, at Diegerloch, about two miles to the south-east of Stuttgart, the molar tooth of a small Triassic mammifer, called by him *Microlestes antiquus.* He inferred its true nature from its

Fig. 392.



Microlestes antiquus, Plieninger. Molar tooth, magnified. Upper Trias. Diegerloch, near Stuttgart, Würtemberg.

a. View of inner side? *b.* Same, outer side?
c. Same in profile. *d.* Crown of same.

double fangs, and from the form and number of the protuberances or cusps on the flat crown; and considering it as predaceous, probably insectivorous, he called it *Microlestes* from μικρος, little, and ληστης, a beast of prey. Soon afterwards he found a second tooth, also at the same locality.

No anatomist had been able to give any feasible conjecture as to the affinities of this minute quadruped until Dr. Falconer, in 1857, recognised an unmistakeable resemblance between its teeth and the two back molars of his new genus *Plagiaulax* (fig. 308, p. 313), from the Purbeck strata. This would lead us to the conclusion that Microlestes was marsupial and plant-eating.

In Würtemberg there are two bone-beds, namely, that containing the Microlestes, which has just been described, which constitutes, as we have seen, the uppermost member of the Trias; and another of still greater extent, and still more rich in the remains of fish and reptiles, which is of older date, intervening between the Keuper and Muschelkalk.

The genera *Saurichthys*, *Hybodus*, and *Gyrolepis* are found in both these breccias, and one of the species, *Saurichthys Mongeoti*, is common to both bone-beds, as is also a remarkable reptile allied to Plesiosaurus, called *Nothosaurus mirabilis.* The

crocodilian saurian called *Belodon* by H. Von Meyer, is another Triassic form, associated at Diegerloch with Microlestes.

TRIAS OF ENGLAND.

Beneath the Lias in the midland and western counties of England, there is a great series of red loams, shales, sandstones, and conglomerates, to which the name of the 'New Red Sandstone formation' was first given to distinguish it from other shales and sandstones called the 'Old Red,' often identical in mineral character, but differing greatly in age, being of earlier date than the Permian and Carboniferous formations. The name of 'Red Marl' has been incorrectly applied to the red clays of this formation, as before explained (p. 14), for they are remarkably free from calcareous matter. The absence, indeed, of carbonate of lime, as well as the scarcity of organic remains, together with the bright red colour of most of the rocks of this group, causes a strong contrast between it and the Jurassic formations before described.

The group in question is more fully developed in Germany than in England or France. It has been called the Trias by German writers, or the Triple Group, because it is separable into three distinct formations, called the 'Keuper,' the 'Muschelkalk,' and the 'Bunter-sandstein.' Of these the middle division, or the Muschelkalk, is wholly wanting in England, and the uppermost (Keuper) and lowest (Bunter) members of the series are not rich in fossils.

Upper Trias, or Keuper.—In certain grey indurated marls below the bone-bed at Watchet, on the coast of Somersetshire, Mr. Boyd Dawkins has found a molar tooth of Microlestes, enabling him to refer to the Trias strata formerly classed with the Lias. Mr. Charles Moore had previously discovered many teeth of the same mammifer near Frome, in Somersetshire, in the contents of a vertical vein or fissure traversing a mass of carboniferous limestone. The top of this fissure must have communicated with the bed of the Triassic sea, and probably at a point not far from the ancient shore on which the small marsupials of that era abounded.

This upper division of the Trias called the Keuper is of great thickness in the central counties of England, attaining, according to Mr. Hull's estimate, no less than 3,450 feet in Cheshire, and it covers a large extent of country between Lancashire and Devonshire.

In Worcestershire and Warwickshire in sandstone belonging to the uppermost part of the Keuper the bivalve crustacean

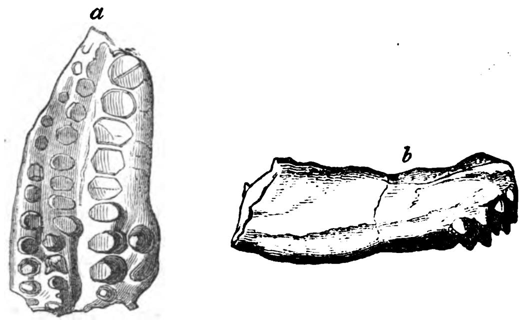
Estheria minuta occurs. The member of the English 'New Red' containing this shell, in those parts of England, is, according to Sir Roderick Murchison and Mr. Strickland, 600 feet thick, and consists chiefly of red marl or slate, with a band of sandstone. Icthyodorulites, or spines of *Hybodus*, teeth of fishes, and footprints of reptiles were observed by the same geologists in these strata.

Fig. 393.

Estheria minuta, Bronn.
Mag. 2 diams.

In the Upper Trias or Keuper the remains of four saurians have been found. The one called *Rhynchosaurus* occurred at Grinsell near Shrewsbury, and is characterised by having a small bird-like skull and jaws without teeth. The other three, *Telerpeton*, *Hyperodapedon*, and the crocodilian reptile *Stagonolepis*, were brought to light near Elgin, in strata formerly

Fig. 394.



Hyperodapedon Gordoni. Left Palate, Maxillary.
(Showing the two rows of palatal teeth on opposite sides of the jaw.)
a. Under surface. *b.* Exterior right side.

supposed to belong to the Old Red Sandstone, but now recognised as Upper Triassic.[2] The *Hyperodapedon* was afterwards discovered in beds of about the same age in the neighbourhood of Warwick, and also in South Devon, and remains of the same genus have been found both in Central India and Southern Africa in rocks believed to be of Triassic age. It has been shown by Professor Huxley to be a terrestrial reptile having numerous palatal teeth, and closely allied to the living *Sphenodon* or *Hatteria* of New Zealand.

The recent discovery of a living saurian in New Zealand so closely allied to this supposed extinct division of the Lacertilia seems to afford an illustration of a principle pointed out by Mr. Darwin of the survival in insulated tracts, after many

[2] See Judd, Quart. Geol. Journ., vol. xxix. p. 142, 1873.

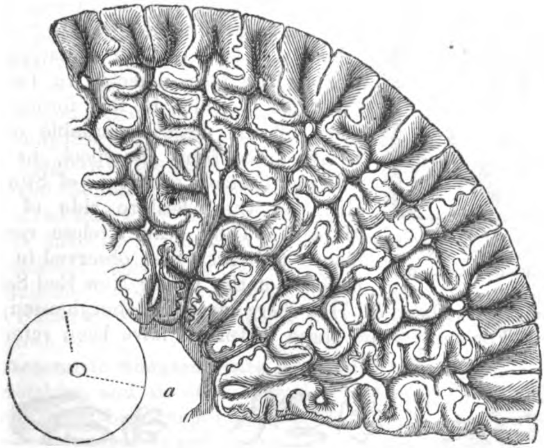
changes in physical geography, of orders of which the congeners have become extinct on continents where they have been exposed to the severer competition of a larger progressive fauna.

In 1842 Professor Owen examined microscopically some teeth of *Labyrinthodon* (fig. 395) from the Keuper in Warwickshire, and discovered in them a structure of extraordinary complexity.[3] The dentinal wall was found to be disposed in many vertical folds, every alternate fold being several times plaited transversely. A cross section of one of these exhibits a series of convolutions, resembling the labyrinthic windings of the surface of the brain, and from this character Professor Owen has proposed the name *Labyrinthodon* for the new genus. The annexed representation (fig. 396) of part of one is given from his 'Odontography,'

Fig. 395.

Tooth of *Labyrinthodon*; nat. size. Warwick sandstone.

Fig. 396.



Transverse section of upper part of tooth of *Labyrinthodon Jaegeri*, Owen (*Mastodonsaurus Jaegeri*, Meyer); natural size, and a segment magnified.
a. Pulp cavity, from which the processes of pulp and dentine radiate.

plate 64 A. The entire length of this tooth is supposed to have been about three inches and a half, and the breadth at the base one inch and a half.

This remarkable structure proved on comparison to characterise not only the genus *Labyrinthodon* but also the allied genus *Mastodonsaurus* of the German Keuper, described p. 365. The

[3] Trans. Geol. Soc., 2nd series, vol. vi. pl. 2.

Labyrinthodonts now constitute a somewhat extensive order of Amphibia of gigantic dimensions in comparison with any representatives of the class now living.

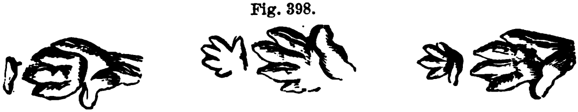
The basement beds of the Keuper rest with a slight unconformability upon an eroded surface of the 'Bunter' next to be described. In these basement beds Professor W. C. Williamson has described the footprints of a *Cheirotherium* similar to those presently to be mentioned in the Bunter beds, but peculiar in exhibiting a scaly structure.[4]

Lower Trias, or Bunter.—The lower division or English representative of the 'Bunter' attains, according to Professor Ramsay, a thickness of 1,500 feet in the counties last mentioned. Besides red and green shales and red sandstones, it comprises much soft white quartzose sandstone, in which the trunks of silicified trees have been met with at Allesley Hill, near Coventry. Several of them were a foot and a half in diameter, and some yards in length, decidedly of coniferous wood, and showing rings of annual growth.[5] Impressions, also, of the footsteps of animals have been detected in Lancashire and Cheshire in this formation. Some of the most remarkable occur a few miles from Liverpool, in the whitish quartzose sandstone of Storton Hill, on the Cheshire side of the Mersey. They bear a close resemblance to tracks first observed in this member of the Upper New Red Sandstone, at the village of Hesseberg, near Hildburghausen, in Saxony. For many years these footprints have been referred to a large unknown quadruped, provisionally named *Cheirotherium* by Professor Kaup, because the marks both of the fore and hind feet resembled impressions made by a human hand (see fig. 397). The footmarks at Hesseberg are partly

Fig. 397.

Single footstep of *Cheirotherium*, Bunter-sandstein, Saxony. One-eighth of natural size.

Fig. 398.



Line of footsteps on slab of sandstone. Hildburghausen, in Saxony.

[4] Quart. Geol. Journ., vol. xxiii. 1867, p. 56.

[5] Buckland, Proc. Geol. Soc., vol. ii. p. 439; and Murchison and Strickland, Geol. Trans. Second Ser., vol. v. p. 347.

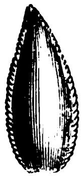
concave, and partly in relief, the former, or the depressions, are seen upon the upper surface of the sandstone slabs, but those in relief are only upon the lower surfaces, being in fact natural casts, formed in the subjacent footprints as in moulds. The larger impressions, which seem to be those of the hind foot, are generally 8 inches in length and 5 in width, and one was 12 inches long. Near each large footstep, and at a regular distance (about an inch and a half) before it, a smaller print of a fore foot, 4 inches long and 3 inches wide, occurs. The footsteps follow each other in pairs, each pair in the same line, at intervals of 14 inches from pair to pair. The large as well as the small steps show the great toes alternately on the right and left side; each step makes the print of five toes, the first or great toe being bent inwards like a thumb. Though the fore and hind foot differ so much in size, they are nearly similar in form.

As neither in Germany nor in England had any bones or teeth been met with in the same identical strata as the footsteps, anatomists indulged for several years in various conjectures respecting the mysterious animals from which they might have been derived. Professor Kaup suggested that the unknown quadruped might have been allied to the *Marsupialia*; for in the kangaroo the first toe of the fore foot is in a similar manner set obliquely to the others, like a thumb, and the disproportion between the fore and hind feet is also very great. But M. Link conceived that some of the four species of animals of which the tracks have been found in Saxony might have been gigantic *Batrachians*; and when it was afterwards inferred that the Labyrinthodon was an air-breathing reptile it was conjectured by Professor Owen that it might be one and the same as the Cheirotherium.

Dolomitic Conglomerate of Bristol.—Near Bristol, in Somersetshire, and in other counties bordering the Severn, the lowest strata belonging to the Triassic series consist of a conglomerate or breccia resting unconformably upon the Old Red Sandstone, and on different members of the Carboniferous rocks such as the Coal Measures, Millstone Grit, and Mountain Limestone. This mode of superposition will be understood by reference to the section below Dundry Hill (fig. 85, p. 109), where No. 4 is the dolomitic conglomerate. Such breccias may have been partly the result of the subaërial waste of an old landsurface which gradually sank down and suffered littoral denudation in proportion as it became submerged. The pebbles and fragments of older rocks which constitute the conglomerate are cemented together by a red or yellow base of dolomite, and in

some places the encrinites, corals, brachiopoda, and other fossils derived from the Mountain Limestone are so detached from the parent rocks that they have the deceptive appearance of belonging to a fauna contemporaneous with the dolomitic beds in which they occur. The imbedded fragments are both rounded and angular, some consisting of carboniferous limestone and millstone grit, being of vast size, and many weighing nearly a ton. Fractured bones and teeth of saurians which are truly of contemporaneous origin have been found in the lower part of the breccia, and two of these, called *Thecodontosaurus* and *Palæosaurus*, from the manner in which the teeth were implanted in the jawbone, obtained great celebrity because the patches of red conglomerate in which they were found, at Durdham Down, near Bristol, were originally supposed to be of Permian or Palæozoic age, and therefore the only representatives in England of vertebrate animals of so high a type in rocks of such antiquity. The teeth of these saurians are conical, compressed, and with finely serrated edges (see fig. 399); they are referred by Professor Huxley to the Dinosauria.

Fig. 399.



Tooth of *Thecodontosaurus*; 3 times magnified, Riley and Stutchbury, Dolomitic conglomerate. Durdham Down, near Bristol.

Origin of Red Sandstone and Rock Salt.—In Cheshire and Lancashire there are red clays containing gypsum and salt of the age of the Trias which are between 1,000 and 1,500 feet thick. In some places lenticular masses of pure rock salt nearly 100 feet thick are interpolated between the argillaceous beds. At the base of the formation beneath the rock salt occur the Lower Sandstones and Marl, called provincially in Cheshire 'water-stones,' which are largely quarried for building. They are often ripple-marked, and are impressed with numerous footprints of reptiles.

As in various parts of the world red and mottled clays and sandstones, of several distinct geological epochs, are found associated with salt, gypsum, and magnesian limestone, or with one or all of these substances, there is, in all likelihood, a general cause for such a coincidence. Nevertheless, we must not forget that there are dense masses of red and variegated sandstones and clays, thousands of feet in thickness, and of vast horizontal extent, wholly devoid of saliferous or gypseous matter. There are also deposits of gypsum and of common salt, as in the blue clay formation of Sicily, without any accompanying red sandstone or red clay.

These red deposits may be accounted for by the decomposition of gneiss and mica schist, which in the eastern Grampians

of Scotland has produced a mass of detritus of precisely the same colour as the New Red Sandstone.

It is a general fact, and one not yet accounted for, that scarcely any fossil remains are ever preserved in stratified rocks in which this oxide of iron abounds; and when we find fossils in the New or Old Red Sandstone in England, it is in the gray, and usually calcareous beds, that they occur. The saline or gypseous interstratified beds may have been produced by submarine gaseous emanations, or hot mineral springs which often continue to flow in the same spots for ages. Beds of rock salt are, however, more generally attributed to the evaporation of lakes or lagoons communicating at intervals with the ocean. In Cheshire two beds of salt occur of the extraordinary thickness of 90 or even 100 feet, and extending over an area supposed to be 150 miles in diameter. The adjacent beds present ripple-marked sandstones and footprints of animals at so many levels as to imply that the whole area underwent a slow and gradual depression during the formation of the red sandstone. Professor Ramsay has remarked in regard to the Trias that it was probably a Continental Period with many inland lakes and seas, the Keuper marls of the British Isles having been deposited in a great lake, fresh or brackish, at the beginning and afterwards rendered salt by evaporation. 'Were the rainfall,' he observes, 'of the area drained by the Jordan to increase gradually, the basin of the Dead Sea would by degrees fill with water, and successive deposits of sediment would gradually overlap each other on the shelving slopes of the lake-basin in which solid salts had previously been deposited. There are examples of this kind of overlap in the New Red Marl of England, in Somerset, Gloucester, Hereford, and Leicester.'[6] Professor Ramsay has pointed out that ferruginous mud and ores of iron are deposited in some of the lakes of Sweden at the present day. These are periodically dredged for economic purposes by the proprietors till the layer is exhausted, and after a sufficient interval they renew their dredging operations and new deposits are found. He therefore suggests that the red peroxide may in itself be an indication of lacustrine conditions, for each grain of sand and mud is encrusted with a thin pellicle of peroxide of iron, which he thinks could not have taken place in a wide and deep sea.[7] This theory of the Continental origin of the Trias derives some confirmation from the fact that the earliest terrestrial mammalia (*Microlestes*) yet discovered in Europe and America (see pp. 356, 373) are of Triassic date.

[6] Quart. Geol. Journ., 1871, vol. xxvii. p. 196.

[7] Contemporary Review, July 1873, p. 201.

Major Harris, in his 'Highlands of Ethiopia,' describes a salt lake, called the Bahr Assal, near the Abyssinian frontier, which once formed the prolongation of the Gulf of Tadjara, but was afterwards cut off from the gulf by a broad bar of lava. 'Fed by no rivers, and exposed in a burning climate to the unmitigated rays of the sun, it has shrunk into an elliptical basin seven miles in its transverse axis, half filled with smooth water of the deepest cærulean hue, and half with a solid sheet of glittering snow-white salt, the offspring of evaporation.' 'If,' says Mr. Hugh Miller, 'we suppose, instead of a barrier of lava, that sand-bars were raised by the surf on a flat arenaceous coast during a slow and equable sinking of the surface, the waters of the outer gulf might occasionally topple over the bar, and supply fresh brine when the first stock had been exhausted by evaporation.'[8]

The Runn of Cutch, as I have shown elsewhere,[9] is a low region near the delta of the Indus, equal in extent to about a quarter of Ireland, which is neither land nor sea, being dry during part of every year, and covered by salt water during the monsoons. Here and there its surface is encrusted over with a layer of salt caused by the evaporation of sea water. A subsiding movement has been witnessed in this country during earthquakes, so that a great thickness of pure salt might result from a continuation of such sinking.

TRIAS OF GERMANY.

In Germany, as before hinted, p. 357, the Trias first received its name as a Triple Group, consisting of two sandstones with an intermediate marine calcareous formation, which last is wanting in England.

NOMENCLATURE OF TRIAS.

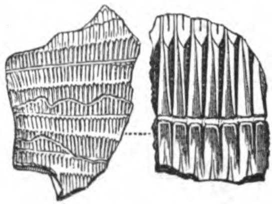
German	French	English
Keuper	Marnes irisées	Saliferous and gypseous shales and sandstone.
Muschelkalk	Muschelkalk, ou calcaire coquillier	wanting in England.
Bunter-Sandstein.	Grès bigarré	Sandstone and quartzose conglomerate.

[8] Hugh Miller, First Impressions of England, 1847, pp. 183, 214.

[9] Principles of Geology, chap. xxvii.

Keuper.—The first of these, or the Keuper, underlying the beds before described as Rhætic, attains in Würtemberg a thickness of about 1,000 feet. It is divided by Alberti into sandstone, gypsum, and carbonaceous clay-slate.[1] In this formation, in the year 1828, Prof. Jaeger, of Stuttgart, found some gigantic conical teeth with vertically ribbed sides, to which he gave the name of *Mastodonsaurus*; and a fragment of a large skull, comprising two well-ossified occipital condyles, which was named Salamandroides. Prof. Jaeger regarded the former as a saurian, and the latter as an amphibian; but both have since been proved to belong to one genus, for which the name *Mastodonsaurus* has been retained.[2] Other remains of reptiles called *Nothosaurus* and *Phytosaurus*, have also been found, and the detached teeth of placoid fish of the genera *Saurichthys* and *Gyrolepis* (figs. 390, 391, p. 355). The plants of the Keuper are generically very analogous to those of the oolite and lias, consisting of ferns, equisetaceous plants, cycads, and conifers, with a few doubtful monocotyledons. A few species, among which is *Equisetum arenaceum*, are common to this group and the oolite.

Fig. 400.



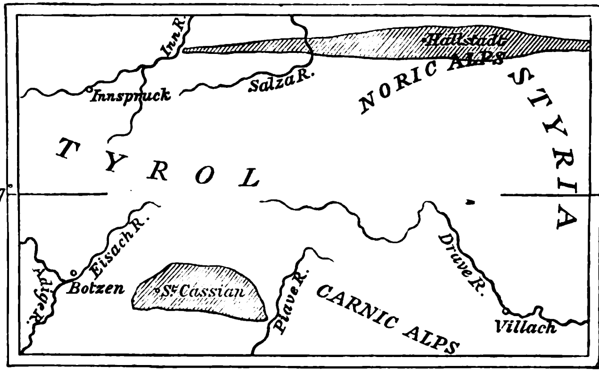
Equisetum arenaceum. Fragment of stem, and a small portion of same magnified. Keuper.

St. Cassian and Hallstadt Beds (see map, fig. 401, p. 366).—The sandstones and clay of the Keuper afford, in the N.W. of Germany, as in France and England, but a scanty representation of the marine life of that period. We might, however, have anticipated, from its rich reptilian fauna, that the contemporaneous inhabitants of the sea of the Keuper period would be very numerous, should we ever have an opportunity of bringing their remains to light. This, it is believed, has at length been accomplished by the position now assigned to certain Alpine rocks called the 'St. Cassian beds,' the true place of which in the series was until lately a subject of much doubt and discussion. It has been proved that the Hallstadt beds on the northern flanks of the Austrian Alps correspond in age with the St. Cassian beds on their southern declivity, and the Austrian geologists, M. Suess of Vienna, and others, have satisfied themselves that the Hallstadt formation is referable to the period of the Upper Trias. Assuming this conclusion to be correct, we become acquainted suddenly and unexpectedly with a rich

[1] Monog. des Bunter-Sandsteins.
[2] Jaeger, Ueber die fossilen Reptilien von Würtemberg. Stuttgart, 1828.

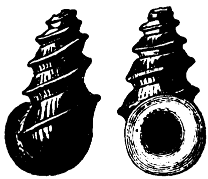
marine fauna belonging to a period previously supposed to be very barren of organic remains, because in England, France, and

Fig. 401.



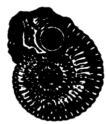
Northern Germany the Upper Trias is chiefly represented by beds of fresh or brackish water origin.

Fig. 402.



Scoliostoma, St. Cassian.

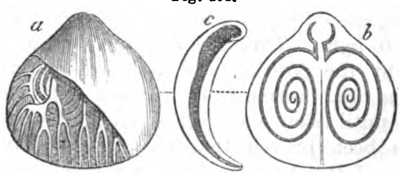
Fig. 403.



Platystoma Suessii, Hörnes. From Hallstadt.

About 600 species of invertebrate fossils occur in the Hall-

Fig. 404.



Koninckia Leonhardi, Wissmann.

a. Ventral view. Part of ventral valve removed to show the vascular impressions of dorsal valve.
b. Interior of dorsal valve, showing spiral processes restored.
c. Vertical section of both valves. Part shaded black showing place occupied by the animal, and the dorsal valve following the curve of the ventral.

stadt and St. Cassian beds, many of which are still undescribed; some of the Mollusca are of new and peculiar genera, as *Scolio-*

stoma (fig. 402) and *Platystoma* (fig. 403) among the Gasteropoda ; and *Koninckia* (fig. 404) among the Brachiopoda.

The following table of genera of marine shells from the Hallstadt and St. Cassian beds, drawn up first on the joint authority of M. Suess and the late Dr. Woodward, and since corrected by Messrs. Etheridge and Tate, shows how many connecting links between the fauna of primary and secondary (Palæozoic and Mesozoic) rocks are supplied by the St. Cassian and Hallstadt beds.

GENERA OF FOSSIL MOLLUSCA IN THE ST. CASSIAN AND HALLSTADT BEDS.

Common to Older Rocks.	Characteristic Triassic Genera.	Common to Newer Rocks.
Orthoceras	Ceratites	Ammonites
Bactrites	Cochloceras	Chemnitzia
Machrocheilus	Choristoceras	Cerithium
Loxonema	Rhabdoceras	Monodonta
Holopella	Aulacoceras	Opis
Murchisonia	*Scoliostoma	Sphœra
	Naticella	Cardita
Porcellia	Platystoma	Myoconcha
Athyris	Ptychostoma	Hinnites
Retzia	Euchrysalis	Monotis
Cyrtina	Halobia	Plicatula
Euomphalus	Hörnesia	Pachyrisma
	Amphiclina	Thecidium
	Koninckia	
	**Cassianella	
	**Myophoria	

The first column marks the last appearance of several genera which are characteristic of Palæozoic strata. The second shows those genera which are characteristic of the Upper Trias, either as peculiar to it or, as in the three cases marked by asterisks, reaching their maximum of development at this era. The third column marks the first appearance in Triassic rocks of genera destined to become more abundant in later ages.

It is only, however, when we contemplate the number of species by which each of the above-mentioned genera are represented that we comprehend the peculiarities of what is commonly called the St. Cassian fauna. Thus, for example, the Ammonite,

* Reaches its maximum in the Trias, but passes down to older rocks.

** Reach their maximum in the Trias, but pass up to newer rocks.

which is not common to older rocks, is represented by no less than seventy-three species; whereas Loxonema, which is only known as common to older rocks, furnishes fifteen Triassic species. Cerithium, so abundant in tertiary strata, and which still lives, is represented by no less than fourteen species. As the Orthocera had never been met with in the marine Muschelkalk, much surprise was naturally felt that seven or eight species of the genus should appear in the Hallstadt beds, assuming these last to belong to the Upper Trias. Among these species are some of large dimensions, associated with large Ammonites with foliated lobes, a form never seen before so low in the series, while the Orthoceras had never been seen so high.

On the whole, the rich marine fauna of Hallstadt and St. Cassian, now generally assigned to the lowest members of the Upper Trias or Keuper, leads us to suspect that when the strata of the Triassic age are better known, especially those belonging to the period of the Bunter Sandstone, the break between the Palæozoic and Mesozoic Periods may be almost effaced. Indeed some geologists are not yet satisfied that the true position of the St. Cassian beds (containing so great an admixture of types having at once both Mesozoic and Palæozoic affinities) is made out, and doubt whether they have yet been clearly proved to be newer than the Muschelkalk.

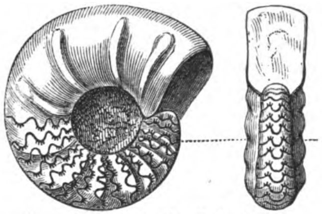
A rich fauna, comprising 225 species, of which about one-fourth are identical with those of St. Cassian, has been brought to light at D'Esino, in Lombardy, and has been admirably illustrated by Professor Stoppani.[3] He describes 65 species of the genus of spiral univalve Chemnitzia, reminding us by its abundance of the Cerithia of the Paris basin, while the enormous size of some specimens would almost bear comparison with the *Cerithium giganteum* of that Eocene formation.

Muschelkalk.—The next member of the Trias in Germany, the *Muschelkalk*, which underlies the *Keuper* before described, consists chiefly of a compact greyish limestone, but includes beds of dolomite in many places, together with gypsum and rock salt. This limestone—a formation, perhaps, wholly unrepresented in England—abounds in fossil shells, as the name implies. Among the Cephalopoda there are no belemnites, and no ammonites with completely foliated sutures, as in the Lias and Oolite and the Hallstadt beds; but we find instead a genus allied to the Ammonite (fig. 405), called *Ceratites* by De Haan, in which the descending lobes of the septa dividing the chambers terminate in a few small denticulations or sutures pointing in-

[3] Stoppani, Les Pétrifactions d'Esino. Milan, 1858–1860.

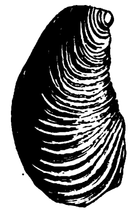
wards. Among the bivalve crustacea, the *Estheria minuta*, Bronn (see fig. 393, p. 358), is abundant, ranging through the

Fig. 405.



Ceratites nodosus, Schloth, ½. Muschelkalk, Germany. Side and front view, showing the denticulated outline of the septa dividing the chambers.

Fig. 406.

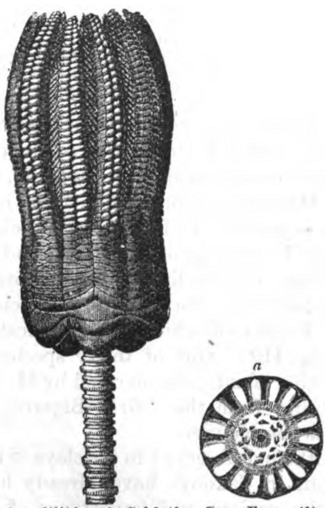


Gervillia (Avicula) socialis. Schloth, nat. size. Characteristic shell of the Muschelkalk.

Keuper and Muschelkalk; and *Gervillia socialis* (fig. 406), having a similar range, is found in great numbers in the Muschelkalk of Germany, France, and Poland.

The abundance of the heads and stems of lily encrinites,

Fig. 407.



Encrinus liliiformis, Schloth. Syn. *E. moniliformis*, ⅔. Body, arms, and part of stem. *a.* Section of stem. Muschelkalk.

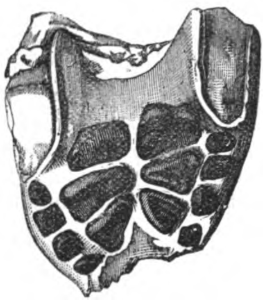
Fig. 408.

Aspidura loricata, Agass. *a.* Upper side. *b.* Lower side. Muschelkalk.

Encrinus liliiformis (fig. 407) (or *Encrinites moniliformis*), shows the slow manner in which some beds of this limestone have been formed in clear sea water. The star-fish called *Aspidura lori-*

cata (fig. 408) is as yet peculiar to the Muschelkalk. In the same formation are found the skull and teeth of a reptile of the genus *Placodus* (see fig. 409), which was referred originally by Münster, and afterwards by Agassiz, to the class of fishes. But more perfect specimens enabled Professor Owen, in 1858, to show that this fossil was a Saurian, which probably fed on shell-bearing mollusks, and used its short and flat teeth, so thickly coated with enamel, for pounding and crushing the shells.

Fig. 409.



Palatal teeth of *Placodus gigas*.
Muschelkalk.

Fig. 410.

a. Voltzia heterophylla. (Syn. *Voltzia brevifolia.*)
b. Portion of same magnified to show fructification. Sulzbad.
Bunter-sandstein.

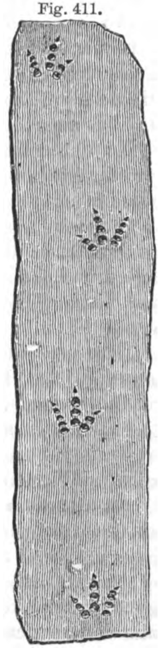
Bunter-sandstein.—The *Bunter-sandstein* consists of various-coloured sandstones, dolomites, and red clays, with some beds, especially in the Hartz, of calcareous pisolite or roe-stone, the whole sometimes attaining a thickness of more than 1,000 feet. The sandstone of the Vosges is proved, by its fossils, to belong to this lowest member of the Triassic group. At Sulzbad (or Saultz-les-Bains), near Strasburg, on the flanks of the Vosges, many plants have been obtained from the 'Bunter,' especially conifers of the extinct genus *Voltzia*, of which the fructification has been preserved. (See fig. 410.) Out of thirty species of ferns, cycads, conifers, and other plants, enumerated by M. Ad. Brongniart, in 1849, as coming from the 'Grès Bigarré,' or Bunter, not one is common to the Keuper.

The footprints of Labyrinthodon observed in the clays of this formation at Hildburghausen, in Saxony, have already been mentioned. Some idea of the variety and importance of the terrestrial vertebrate fauna of the three members of the Trias in Northern Germany may be derived from the fact that in the great monograph by the late Hermann von Meyer on the reptiles of the Trias, the remains of no less than eighty distinct species are described and figured.

TRIAS OF THE UNITED STATES.

New Red Sandstone of the Valley of the Connecticut River.—In a depression of the granitic or hypogene rocks in the States of Massachusetts and Connecticut, strata of red sandstone, shale, and conglomerate are found, occupying an area more than 150 miles in length from north to south, and about 5 to 10 miles in breadth, the beds dipping to the eastward at angles varying from 5 to 50 degrees. The extreme inclination of 50 degrees is rare, and only observed in the neighbourhood of masses of trap which have been intruded into the red sandstone while it was forming, or before the newer parts of the deposit had been completed. Having examined this series of rocks in many places, I feel satisfied that they were formed in shallow water, and for the most part near the shore, and that some of the beds were from time to time raised above the level of the water, and laid dry, while a newer series, composed of similar sediment, was forming.

Fig. 411.



Footprints of a bird. Turner's Falls, Valley of the Connecticut.

According to Professor Hitchcock, the footprints of no less than thirty-two species of bipeds, and twelve of quadrupeds, have been already detected in these rocks. Thirty of these are believed to be those of birds, four of lizards, two of chelonians, and six of batrachians. The tracks have been found in more than twenty places, scattered through an extent of nearly 80 miles from north to south, and they are repeated through a succession of beds attaining at some points a thickness of more than 1,000 feet.[4]

The bipedal impressions are for the most part trifid, and show the same number of joints as exist in the feet of living tridactylous birds. Now, such birds have three phalangeal bones for the inner toe, four for the middle, and five for the outer one (see fig. 411); but the impression of the terminal joint is that of the nail only. The fossil footprints exhibit regularly, where the joints are seen, the same number; and we see in each continuous line of tracks the three-jointed and five-jointed toes placed alternately outwards, first on the one side and then on

[4] Hitchcock, Mem. of Amer. Acad., New Series, vol. iii. p. 129. 1848.

the other. In some specimens, besides impressions of the three toes in front, the rudiment is seen of the fourth toe behind. It is not often that the matrix has been fine enough to retain impressions of the integument or skin of the foot; but in one fine specimen found at Turner's Falls on the Connecticut, by Dr. Deane, these markings are well preserved, and have been recognised by Professor Owen as resembling the skin of the ostrich, and not that of reptiles.

The casts of the footprints show that some of the fossil bipeds of the red sandstone of Connecticut had feet four times as large as the living ostrich, but scarcely perhaps larger than the Dinornis of New Zealand, a lost genus of feathered giants related to the Apteryx, of which there were many species which have left their bones and almost entire skeletons in the superficial alluvium of that island. By referring to what was said of the Iguanodon of the Wealden the reader will perceive that the Dinosaur was somewhat intermediate between reptiles and birds and left a series of tridactylous impressions on the sand.

To determine the exact age of the red sandstone and shale containing these ancient footprints in the United States is not possible at present. No fossil shells have yet been found in the deposit, nor plants in a determinable state. The fossil fish are numerous and very perfect; but they are of a peculiar type, called *Ischypterus*, by Sir Philip Egerton, from the great size and strength of the fulcral rays of the dorsal fin, from ἰσχὺς, strength, and πτερὸν, a fin.

The age of the Connecticut beds cannot be proved by direct superposition, but may be presumed from the general structure of the country. That structure proves them to be newer than the movements to which the Appalachian or Alleghany chain owes its flexures, and this chain includes the ancient or palæozoic coal-formation among its contorted rocks.

Coal-field of Richmond, Virginia.—In the State of Virginia, at the distance of about 13 miles eastward of Richmond, the capital of that State, there is a coal-field occurring in a depression of the granite rocks, and occupying a geological position analogous to that of the new Red Sandstone, above mentioned, of the Connecticut Valley. It extends 26 miles from north to south, and from 4 to 12 from east to west.

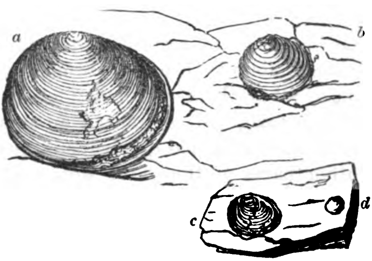
The plants consist chiefly of zamites, calamites, equiseta, and ferns, and upon the whole are considered by Professor Heer to have the nearest affinity to those of the European Keuper.

The equiseta are very commonly met with in a vertical positiou more or less compressed perpendicularly. It is clear that they grew in the places where they are now buried in strata of

hardened sand and mud. I found them maintaining their erect attitude, at points many miles apart, in beds both above and between the seams of coal. In order to explain this fact we must suppose such shales and sandstones to have been gradually accumulated during the slow and repeated subsidence of the whole region.

The fossil fish are Ganoids, some of them of the genus *Catopterus*, others belonging to the liassic genus *Tetragonolepis* (*Æchmodus*) (see fig. 379, p. 345). Two species of *Entomostraca* called *Estheria* are in such profusion in some shaly beds as to divide them like the plates of mica in micaceous shales (see fig. 412).

Fig. 412.



a. Estheria ovata. *b.* Young of same.
c. Natural size of *a.* *d.* Natural size of *b.*
Triassic coal-shale, Richmond, Virginia.

These Virginian coal-measures are composed of grits, sandstones, and shales, exactly resembling those of older or primary date in America and Europe, and they rival or even surpass the latter in the richness and thickness of the coal-seams. One of these, the main seam, is in some places from 30 to 40 feet thick, composed of pure bituminous coal. The coal is like the finest kinds shipped at Newcastle, and when analysed yields the same proportions of carbon and hydrogen—a fact worthy of notice when we consider that this fuel has been derived from an assemblage of plants very distinct specifically, and in part generically, from those which have contributed to the formation of the ancient or palæozoic coal.

Triassic mammifer.—In North Carolina, the late Professor Emmons has described the strata of the Chatham coal-field, which correspond in age to those near Richmond in Virginia. In beds underlying them he has met with three jaws of a small insectivorous mammal, which he has called *Dromatherium sylvestre*, closely allied to *Spalacotherium* from the Middle Purbeck. Its nearest living analogue, says Professor Owen, 'is found in

Myrmecobius; for each ramus of the lower jaw contained ten small molars in a continuous series, one canine, and three conical incisors—the latter being divided by short intervals.'

Low grade of early mammals favourable to the theory of progressive development.—There is every reason to believe that this fossil quadruped is at least as ancient as the Microlestes of the European Trias above described, p. 356; and the fact is highly important, as proving that a certain low grade of marsupials had not only a wide range in time from the Trias to the Purbeck or uppermost oolitic strata of Europe, but had also a wide range in space, namely, from Europe to North America, in an east and west direction, and, in regard to latitude, from Stonesfield, in 52° N., to that of North Carolina, in 35° N.

If the three localities in Europe where the most ancient mammalia have been found—Purbeck, Stonesfield, and Stuttgart—had belonged all of them to formations of the same age, we might well have imagined so limited an area to have been peopled exclusively with pouched quadrupeds, just as Australia now is, while other parts of the globe were inhabited by placentals; for Australia now supports one hundred and sixty species of marsupials, while the rest of the continents and islands are tenanted by about seventeen hundred species of mammalia, of which only forty-six are marsupial, namely, the opossums of North and South America. But the great difference of age of the strata in each of these three localities seems to indicate the predominance throughout a vast lapse of time (from the era of the Upper Trias to that of the Purbeck beds) of a low grade of quadrupeds; and this persistency of similar generic and ordinal types in Europe while the species were changing, and while the fish, reptiles, and mollusca were undergoing great modifications, would naturally lead us to suspect that there must also have been a vast extension in space of the same marsupial forms during that portion of the Secondary or Mesozoic epoch which has been termed 'the age of reptiles.' Such an inference as to the wide geographical range of the ancient marsupials has been confirmed by the discovery in the Trias of North America of the above-mentioned Dromatherium. The predominance in earlier ages of these mammalia of a low grade, and the absence, so far as our investigations have yet gone, of species of higher organisation, whether aquatic or terrestrial, is certainly in favour of the theory of progressive development.

PRIMARY OR PALÆOZOIC SERIES.

CHAPTER XXII.

PERMIAN OR MAGNESIAN LIMESTONE GROUP.

Line of separation between Mesozoic and Palæozoic rocks—Distinctness of Triassic and Permian fossils—Term Permian—Thickness of calcareous and sedimentary rocks in North of England—Upper, Middle, and Lower Permian—Marine shells and corals of the English Magnesian Limestone—Reptiles and fish of Permian marl slate—Footprints of reptiles—Angular breccias in Lower Permian—Extent of land in the Permian Period—Permian rocks of the Continent—Zechstein and Rothliegendes of Thuringia—Permian flora—Its generic affinity with the Carboniferous.

In pursuing our examination of the strata in descending order we have next to pass from the base of the Secondary or Mesozoic to the uppermost or newest of the Primary or Palæozoic formations. As this point has been selected as a line of demarcation for one of the three great divisions of the fossiliferous series, the student might naturally expect that by aid of lithological and palæontological characters he would be able to recognise without difficulty a distinct break between the newer and older group. But so far is this from being the case in Great Britain that nowhere have geologists found more difficulty in drawing a line of separation than between the Secondary and Primary series. The obscurity has arisen from the great resemblance in colour and mineral character of the Triassic and Permian red marls and sandstones, and the scarcity and often total absence in them of organic remains. The thickness of the strata belonging to each group amounts in some places to several thousand feet, and by dint of a careful examination of their geological position, and of those fossil animal and vegetable forms which are occasionally met with in some members of each series, it has at length been made clear that the older or Permian rocks are more connected with the Primary or Palæozoic than with the Secondary or Mesozoic strata already described.

The term Permian was proposed for this group by Sir R. Murchison, from Perm, a Russian province, where it occupies an area twice the size of France and contains a great abundance

and variety of fossils both vertebrate and invertebrate. Professor Sedgwick in 1832[1] described what is now recognised as the central member of this group, the Magnesian Limestone, showing that it attained a thickness of 600 feet along the north-east of England, in the counties of Durham, Yorkshire, and Nottinghamshire, its lower part often passing into a fossiliferous marl-slate and resting on an inferior Red Sandstone, the equivalent of the Rothliegendes of Germany. It has since been shown that some of the Red Sandstones of newer date also belong to the Permian group; and it appears from the observations of Mr. Binney, Sir R. Murchison, Mr. Harkness, and others that it is in the region where the limestone is most largely developed, as for example in the county of Durham, that the associated red sandstones or sedimentary rocks are thinnest, whereas in the country where the latter are thickest the calcareous member is reduced to 30 or even sometimes to 10 feet. It is clear, therefore, says Mr. Hull, that the sedimentary region in the North of England area has been to the westward, and the calcareous area to the eastward; and that in this group there has been a development from opposite directions of the two types of strata.

In illustration of this he has given us the following table:—

THICKNESS OF PERMIAN STRATA IN NORTH OF ENGLAND.

	N.W. of England, feet	N.E. of England, feet
Upper Permian (Sedimentary) . .	600	50–100
Middle ,, (Calcareous) . .	10–30	600
Lower ,, (Sedimentary) . .	3,000	100–250[2]

Upper Permian.—What is called in this table the Upper Permian will be seen to attain its chief thickness in the north-west or on the coast of Cumberland, as at St. Bees Head, where it is described by Sir Roderick Murchison as consisting of red sandstones and red clays with gypsum resting on a thin course of Magnesian Limestone with fossils, which again is connected with the Lower Red Sandstones, resembling the upper one in such a manner that the whole forms a continuous series. No fossil footprints have been found in this Upper as in the Lower Red Sandstone.

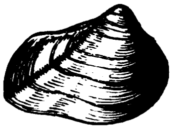
Middle Permian—Magnesian Limestone and Marl-slate.—This formation is seen upon the coast of Durham and Yorkshire, between the Wear and the Tees. Among its characteristic

[1] Trans. Geol. Soc. Lond., Second Series, vol. iii. p. 37.

[2] Edward Hull, Ternary Classification, Quart. Journ. of Science, 1869, No. xxiii.

fossils are *Schizodus Schlotheimi* (fig. 413) and *Mytilus septifer* (fig. 415). These shells occur at Hartlepool and Sunderland, where the rock assumes an oolitic and botryoidal character. Some of the beds in this division are ripple-marked. In some

Fig. 413.

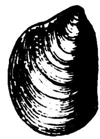


Schizodus Schlotheimi, Geinitz, $\frac{2}{3}$. Permian crystalline limestone.

Fig. 414.

The hinge of *Schizodus truncatus*, King. Permian.

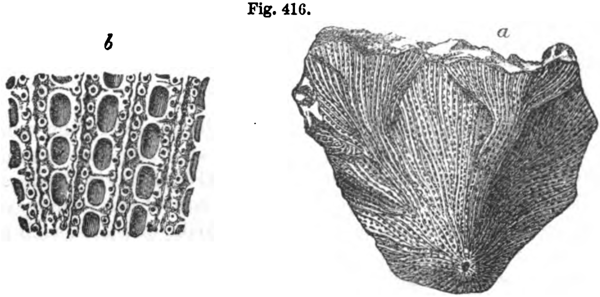
Fig. 415.



Mytilus septifer, King. Syn. *Modiola acuminata*, Sow., nat. size. Permian crystalline limestone.

parts of the coast of Durham, where the rock is not crystalline, it contains as much as 44 per cent. of carbonate of magnesia, mixed with carbonate of lime. In other places—for it is extremely variable in structure—it consists chiefly of carbonate of lime, and has concreted into globular and hemispherical masses, varying from the size of a marble to that of a cannon-ball, and radiating from the centre. Occasionally earthy and pulverulent beds pass into compact limestone or hard granular dolomite. Sometimes the limestone appears in a brecciated form, the fragments which are united together not consisting of foreign rocks, but seemingly composed of the breaking-up of the

Fig. 416.



a. *Fenestella retiformis*, Schloth, sp., nat. size.
Syn. *Gorgonia infundibuliformis*, Goldf.; *Retepora flustracea*, Phillips.
b. Part of the same highly magnified.
Magnesian Limestone, Humbleton Hill, near Sunderland.[3]

Permian limestone itself, about the time of its consolidation. Some of the angular masses in Tynemouth cliff are 2 feet in diameter.

[3] King's Monograph, Pl. 2.

The magnesian limestone sometimes becomes very fossiliferous and includes in it delicate polyzoa, one of which, *Fenestella retiformis* (fig. 416), is a very variable species, and has received many different names. It sometimes attains a large size, single specimens measuring 8 inches in width. The same polyzoan, with four other British species, is also found abundantly in the Permian of Germany.

The total known fauna of the Permian series of Great Britain at present numbers 147 species, of which 77, or more than half, are mollusca. Not one of these is common to rocks newer than the Palæozoic, and the brachiopods are the only group which have furnished species common to the more ancient or Carboniferous rocks. Of these *Lingula Crednerii* (fig. 418) is an example. There are 25 gasteropods and only one cephalopod, *Nautilus Freieslebeni*, which is also found in the German Zechstein.

Shells of the genera *Productus* (fig. 417) and *Strophalosia* (the latter of allied form with hinge teeth), which do not occur in strata newer than the Permian, are abundant in the

Fig. 417.

Productus horridus, Sowerby, $\frac{1}{2}$. (*P. Calvus*, Sow.) Sunderland and Durham, in Magnesian Limestone. Zechstein and Kupferschiefer, Germany.

Fig. 418.

Lingula Crednerii. (Geinitz.) Magnesian Limestone and Carboniferous. Marl-slate, Durham; Zechstein, Thuringia.

Fig. 419.

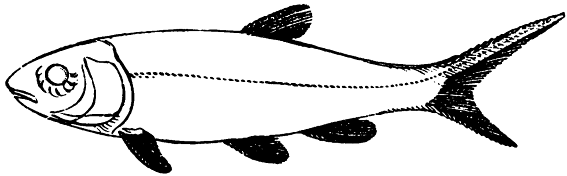
Spirifera alata, Schloth., $\frac{2}{3}$. Syn. *Trigonotreta undulata*, Sow. King's Monogr. Magnesian limestone.

ordinary yellow magnesian limestone, as will be seen in the valuable memoirs of Messrs. King and Howse. They are accompanied by certain species of *Spirifera* (fig. 419), *Lingula Crednerii* (fig. 418), and other brachiopoda characteristic of the primary or palæozoic formations. Some of this same tribe of shells, such as *Camarophoria* allied to *Rhynchonella*, *Spiriferina*, and two species of *Lingula*, are specifically the same as fossils of the Carboniferous rocks. *Avicula*, *Arca*, and *Schizodus* (fig. 413), and other lamellibranchiate bivalves, are abundant, but spiral univalves are very rare.

Beneath the limestone lies a formation termed the marl-slate, which consists of hard, calcareous shales, marl-slate and thin-bedded limestones. At East Thickley, in Durham, where it is thirty feet thick, this slate has yielded many fine specimens of fossil fish—of the genera *Palæoniscus* 10 species, *Pygopterus* 2

species, *Cœlacanthus* 2 species, and *Platysomus* 2 species, which as genera are common to the older Carboniferous formation; but the Permian species are peculiar, and, for the most part, identical with those found in the marl-slate or copper-slate of Thuringia.

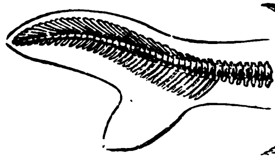
Fig. 420.



Restored outline of a fish of the genus *Palæoniscus*, Agass. *Palæothrissum*, Blainville.

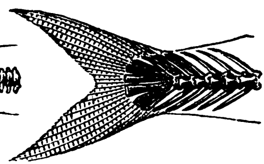
The *Palæoniscus* above mentioned belongs to that division of fishes which M. Agassiz has called 'Heterocercal,' which usually have their tails unequally bilobate, like the recent shark and sturgeon, and the vertebral column running along the upper caudal lobe. (See fig. 421.) The 'Homocercal' fish, which comprise almost all the 9,000 species at present known living,

Fig. 421.



Shark.
Heterocercal.

Fig. 422.



Shad. (*Clupea*. Herring tribe.)
Homocercal.

have the tail-fin either single or equally divided; and the vertebral column stops short, and is not prolonged into either lobe. (See fig. 422.) Now it is a singular fact, first pointed out by Agassiz, that the heterocercal form, which is confined to a small number of existing genera, is universal in the magnesian limestone, and all the more ancient formations. It characterises the earlier periods of the earth's history, whereas in the secondary strata, or those newer than the Permian, the homocercal tail greatly predominates.

In Prof. King's monograph before referred to, a full description has been given by Sir Philip Egerton of the species of fish characteristic of the marl-slate; and figures of the ichthyolites, which are very entire and well preserved, will be found in the same memoir. Even a single scale is usually so characteristically

marked as to indicate the genus, and sometimes even the particular species. They are often scattered through the beds singly, and may be useful to a geologist in determining the age of the rock.

SCALES OF FISH. MAGNESIAN LIMESTONE.

Fig. 423.

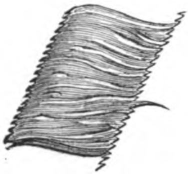


Fig. 424.

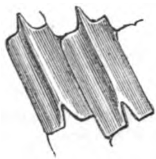


Fig. 425.

Fig. 426.

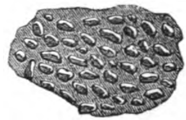
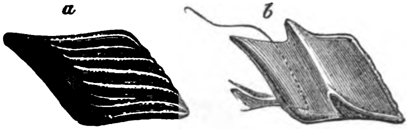


Fig. 423. *Palæoniscus comptus*, Agassiz. Scale, magnified. Marl-slate.
Fig. 424. *Palæoniscus elegans*, Sedg. Under surface of scale, magnified. Marl-slate.
Fig. 425. *Palæoniscus glaphyrus*, Ag. Under surface of scale, magnified. Marl-slate.
Fig. 426. *Cœlacanthus granulatus*, Ag. Granulated surface of scale, magnified. Marl-slate.

Fig. 427.



Pygopterus mandibularis, Ag. Marl-slate.
a. Outside of scale, magnified.
b. Under surface of same.

Fig. 428.

Acrolepis Sedgwickii, Ag.
Outside of scale, magnified.
Marl-slate.

We are indebted to Mr. Joseph Duff, of Bishop's Auckland, as mentioned by Messrs. Hancock and Howse, for the discovery in this marl-slate at Midderidge, Durham, of two species of *Protorosaurus*, a genus of reptiles, one representative of which, *P. Speneri*, has been celebrated ever since the year 1810 as characteristic of the Kupfer-schiefer or Permian of Thuringia. Professor Huxley informs us that the agreement of one of the Durham fossils with Hermann von Meyer's figure of the German specimen is most striking. Although the head is wanting in all the examples yet found, they clearly belong to the Lacertian order, and are therefore of a higher grade than any other vertebrate animal hitherto found fossil in a Palæozoic rock. Remains of a Labyrinthodont, *Lepidotosaurus Duffii*,[4] have been met with in the same slate near Durham; and a quarry in the Permian sandstone of Kenilworth has yielded the skull of

Hancock and Howse, Quart. Geol. Journ., vol. xxvi. pl. xxxviii.

another species called by Professor Huxley *L. Dasyceps*, on account of the roughness of the surface of the cranium.

Lower Permian.—The beds which lie beneath the marl-slate consist of sandstone and sand, separating the Magnesian Limestone from the coal, in Yorkshire and Durham. In some instances, red marl and gypsum have been found associated with these beds. They have been classed with the Magnesian Limestone by Professor Sedgwick, as being nearly co-extensive with it in geographical range, though their relations are very obscure. But the principal development of Lower Permian is, as we have seen by Mr. Hull's table (p. 376), in the north-west, where the Penrith sandstone, as it has been called, and the associated breccias and purple shales are estimated by Professor Harkness to attain a thickness of 3,000 feet. Organic remains are generally wanting, foot-prints and worm-tracks are occasionally met with, and the leaves, cones, and wood of coniferous plants have been found in beds considered by Professor Harkness to be the equivalent of the marl-slate which overlies the Penrith sands at Hilton. Also in the red sandstones of Corncockle Muir near Dumfries very distinct footprints of reptiles occur, originally referred to the Trias, but shown by Mr. Binney in 1856 to be Permian. No bones of the animals which they represent have yet been discovered.

Angular breccias in Lower Permian.—A striking feature in these beds is the occasional occurrence, especially at the base of the formation, of angular and sometimes rounded fragments of Carboniferous and older rocks of the adjoining districts being included in a red matrix. Some of the angular masses are of huge size.

In the central and southern counties, where the Middle Permian or Magnesian Limestone is wanting, it is difficult to separate the upper and lower sandstones, and Mr. Hull is of opinion that the patches of this formation found here and there in Worcestershire, Shropshire, and other counties may have been deposited in a sea separated from the northern basin by a barrier of Carboniferous rocks running east and west, and now concealed under the Triassic strata of Cheshire. Similar breccias to those before described are found in the more southern counties last mentioned, where their appearance is rendered more striking by the marked contrast they present to the beds of well-rolled and rounded pebbles of the Trias occupying a large area in the same region.

Professor Ramsay refers the angular form and large size of the fragments composing these breccias to the action of floating ice in the sea. These masses of angular rock, some of them

weighing more than half a ton, and lying confusedly in a red unstratified marl, like stones in boulder-drift, are in some cases polished, striated, and furrowed like erratic blocks in the moraine of a glacier. They can be shown in some cases to have travelled from the parent rocks, thirty or more miles distant, and yet not to have lost their angular shape.[5]

Extent of land in the Permian Period.—I have already mentioned, when treating of the Keuper, that Professor Ramsay considers the Triassic strata to have been formed in inland lakes during a Continental period, and he is disposed to believe that similar conditions prevailed during the deposition of the Permian series. The footprints of the vale of Eden, he remarks, the sun-cracks, rain-pittings, and ripplings impressed upon the beds apparently indicate shore-surfaces, and the dwarfed and poverty-stricken nature of the magnesian limestone fossils of the Upper Permian strata of Lancashire, resembles the living molluscan fauna of the Caspian Sea. On the other hand, the Magnesian Limestone of the East of England contains a much richer marine fauna, affording indications of a freer communication with the ocean.[6]

Permian rocks of the Continent.—Germany is the classic ground of the Magnesian Limestone now called Permian. The formation was well studied by the miners of that country a century ago, being known to contain a thin band of dark-coloured cupriferous shale, characterised at Mansfeld in Thuringia by numerous fossil fish. Beneath some variegated sandstones (not belonging to the Trias, though often confounded with it) they came down first upon a dolomitic limestone corresponding to the upper part of our Middle Permian, and then upon a marl-slate richly impregnated with copper pyrites, and containing fish and reptiles (Protorosaurus) identical in species with those of the corresponding marl-slate of Durham. To the limestone they gave the name of Zechstein, and to the marl-slate that of Mergel-schiefer or Kupfer-schiefer. Beneath the fossiliferous group lies the Rothliegendes or Roth-todt-liegendes, meaning the red-lyer or red-dead-lyer, the first name being given to it by the German miners from its colour, and the second because the copper had *died out* when they reached this underlying non-metalliferous member of the series. This red under-lyer is, in fact, a great deposit of red sandstone, breccia, and conglomerate with associated porphyry, basalt, and amygdaloid.

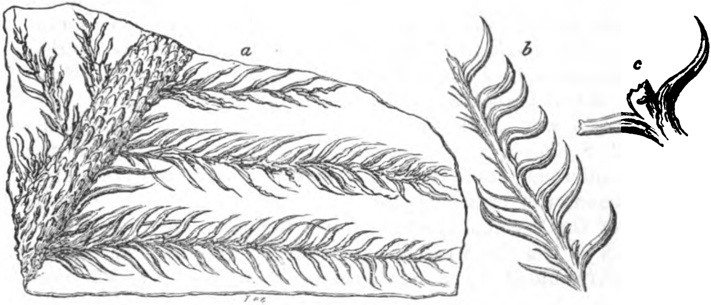
[5] Ramsay, Quart. Geol. Journ. 1855, and Lyell, Principles of Geology, vol. i. p. 223, 10th edit.

[6] Ramsay, Quart. Geol. Journ., vol. xxvii. p. 247.

In Russia, according to Sir R. Murchison, the Permian rocks are composed of white limestone, with gypsum and white salt; and of red and green grits, occasionally with copper ore; also magnesian limestones, marlstones, and conglomerates.

Permian flora.—About 18 or 20 species of plants are known in the Permian rocks of England. None of them pass down

Fig. 429.



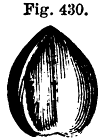
Walchia piniformis, Schloth. Permian, Saxony. Gutbier, Die Versteinerungen des Permischen Systemes in Sachsen, vol. ii. pl. x.) Nat. size.

a. Branch. *b.* Twig of the same. *c.* Leaf magnified.

into the Carboniferous series, but several genera, such as *Alethopteris*, *Neuropteris*, and *Walchia*, are common to the two groups. The Permian flora on the Continent appears, from the researches of MM. Murchison and de Verneuil in Russia, and of MM. Geinitz and von Gutbier in Saxony, to be, with few exceptions, distinct from that of the coal.

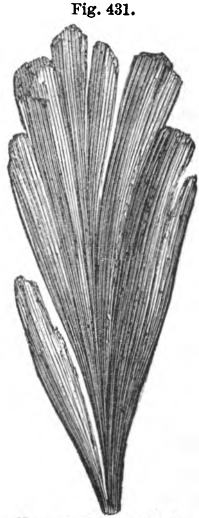
In the Permian rocks of Saxony no less than 60 species of fossil plants have been met with. Two or three of these, as *Calamites gigas*, *Sphenopteris erosa*, and *S. lobata*, are also met with in the government of Perm in Russia. Seven others, and among them *Neuropteris Loshii*, *Pecopteris arborescens*, and *P. similis*, and several species of *Walchia* (see fig. 429), a genus of Conifers called

Fig. 430.



Cardiocarpon Ottonis. Gutbier. Permian, Saxony. ½ diameter.

Fig. 431.



Noeggerathia cuneifolia. Brongniart.[7]

[7] Murchison's Russia, vol. ii. pl. A, fig. 3.

Lycopodites by some authors, are said by Geinitz to be common to the coal-measures.

Among the genera also enumerated by Colonel Gutbier are the fruit called *Cardiocarpon* (see fig. 430), *Asterophyllites*, and *Annularia*, so characteristic of the Carboniferous period; also *Lepidodendron*, which is common to the Permian of Saxony, Thuringia, and Russia, although not abundant. *Noeggerathia* (see fig. 431), the leaves of which have parallel veins without a mid-rib, and to which various generic synonyms, such as *Corduites*, *Flabellaria*, and *Poacites*, have been given, is another link between the Permian and Carboniferous vegetation. Coniferæ, of the Araucarian division, also occur; but these are likewise met with both in older and newer rocks. The plants called *Sigillaria* and *Stigmaria*, so marked a feature in the Carboniferous period, are as yet wanting in the true Permian.

Among the remarkable fossils of the Rothliegendes, or lowest part of the Permian in Saxony and Bohemia, are the silicified trunks of tree-ferns called generically *Psaronius*. Their bark was surrounded by a dense mass of air-roots, which often constituted a great addition to the original stem, so as to double or quadruple its diameter. The same remark holds good in regard to certain living extra-tropical arborescent ferns, particularly those of New Zealand.

Thus we see that while upon the whole the plants of the marl-slate or Middle Permian differ considerably from those of the Coal Period, the plants of the Rothliegende of Germany which belong to the Lower Permian begin to show a very close generic affinity with Carboniferous forms.

CHAPTER XXIII.

THE COAL OR CARBONIFEROUS GROUP.

Principal subdivisions of the Carboniferous Group—Different thickness of the sedimentary and calcareous members in Scotland and the South of England—Coal-measures—Terrestrial nature of the growth of coal—Erect fossil trees—Uniting of many coal-seams into one thick bed—Purity of the coal explained—Conversion of coal into anthracite—Origin of clay ironstone—Marine and brackish-water strata in coal—Fossil insects—Batrachian reptiles—Carboniferous Amphibia—Labyrinthodont foot-prints in coal-measures—Nova Scotia coal-measures with successive growths of erect fossil trees—Structure of American and European coal—Air-breathers of the American coal—Changes of condition of land and sea indicated by the Carboniferous strata of Nova Scotia.

Principal subdivisions of the Carboniferous Group.—The next group which we meet with in descending order is the Carboniferous, commonly called 'The Coal;' because it contains many beds of that mineral, in a more or less pure state, interstratified with sandstones, shales, and limestones. The coal itself, even in Great Britain and Belgium, where it is most abundant, constitutes but an insignificant portion of the whole mass. In South Wales, for example, the thickness of the coal-bearing strata has been estimated at between 11,000 and 12,000 feet, while the various coal-seams, about 80 in number, do not, according to Prof. Phillips, exceed in the aggregate 120 feet.

The carboniferous formation assumes various characters in different parts even of the British Islands. It usually comprises two very distinct members: 1st, the sedimentary beds, usually called the Coal-measures, of mixed freshwater, terrestrial, and marine origin, including seams of coal; 2ndly, that named in England the Mountain or Carboniferous Limestone, of purely marine origin, and made up chiefly of corals, shells, and encrinites, and resting on alternating beds of limestone and shale called the Lower Limestone shale.

In the south-western part of our island, in Somersetshire and South Wales, the three divisions usually spoken of are:—

1. Coal-measures	Strata of shale, sandstone, and grit, from 600 to 10,000 feet thick, with occasional seams of coal.
2. Mill-stone grit	A coarse quartzose sandstone and conglomerate, sometimes used for millstones, with beds of shale; usually devoid of coal; occasionally above 600 feet thick; commonly called 'Farewell Rock.'
3. Mountain or Carboniferous Limestone.	A calcareous rock containing marine shells, corals, and encrinites; thickness variable, sometimes more than 2,000 feet.

If the reader will refer to the section fig. 85, p. 109, he will see that the Upper and Lower Coal-measures of the Coal-field near Bristol are divided by a micaceous flaggy sandstone called the Pennant Rock, about 1,500 feet thick. The Lower Coal-measures of the same section rest on a base of coarse grit called the Millstone Grit (No. 2 of the above table).

In the South Welsh coal-field Millstone Grit occurs in like manner at the base of the productive coal-measures. It is called by the miners the 'Farewell Rock,' as when they reach it they have no longer any hopes of obtaining coal at a greater depth in the same district. In the central and northern coal-fields of England this same Grit, including quartz pebbles, with some accompanying sandstones and shales containing coal plants, acquires a thickness of several thousand feet, lying beneath the productive coal-measures, which are nearly 10,000 feet thick.

Below the Millstone Grit is a continuation of similar sandstones and shales called by Professor Phillips the Yoredale series, from Yoredale, in Yorkshire, where they attain a thickness of from 800 to 1,000 feet. At several intervals bands of limestone divide this part of the series, one of which, called the Main Limestone or Upper Scar Limestone, composed in great part of encrinites, is 70 feet thick. Thin seams of coal also occur in these lower Yoredale beds in Yorkshire, showing that in the same region there were great alternations in the state of the surface. For at successive periods in the same area there prevailed first, terrestrial conditions favourable to the formation of pure coal, secondly, a sea of some depth suited to the formation of Carboniferous Limestone, and, thirdly, a supply of muddy sediment and sand, furnishing the materials for sandstone and shale. There is no clear line of demarcation between the Coal-measures and the Millstone Grit, nor between the Millstone Grit and underlying Yoredale rocks.

On comparing a series of vertical sections in a north-westerly direction from Leicestershire and Warwickshire into North Lancashire we find, says Mr. Hull, within a distance of 120 miles an augmentation of the sedimentary materials to the extent of 16,000 feet.

	Feet
Leicestershire and Warwickshire	2,600
North Staffordshire	9,000
South Lancashire	12,130
North Lancashire	18,700

In central England, where the sedimentary beds are reduced to about 3,000 feet in all, the Carboniferous Limestone attains an enormous thickness, according to Mr. Hull's estimate, as much as 4,000 feet at Ashbourne, near Derby. To a certain extent, therefore, we may consider the calcareous member of the formation as having originated simultaneously with the accumulation of the materials of grit, sandstone, and shale, with seams of coal; just as strata composed of mud, sand, and pebbles, several thousand feet thick, with layers of vegetable matter, are now in the process of formation in the cypress swamps and delta of the Mississippi, while coral reefs are simultaneously forming on the coast of Florida, and in the sea of the Bermuda Islands. For we may safely conclude that in the ancient Carboniferous ocean those marine animals which secreted lime were never freely developed in areas where the rivers poured in fresh water charged with sand or clay; and the limestone could only become several thousand feet thick over parts of the ocean bed, which was being slowly depressed, the water remaining perfectly clear for ages.

The calcareous strata of the Scotch coal-fields, those of Lanarkshire, the Lothians, and Fife for example, are very insignificant in thickness when compared to those of England. They consist of a few beds intercalated between the sandstones and shales containing coal and ironstone, the combined thickness of all the limestones amounting to no more than 150 feet. The vegetation of some of these northern sedimentary beds containing coal may be older than any of the coal-measures of central and southern England as being coeval with the Mountain Limestone of the south. In Ireland the limestone predominates over the coal-bearing sands and shales. We may infer the former continuity of several of the coal-fields in northern and central England, not only from the abrupt manner in which they are cut off at their outcrop, but from their remarkable correspondence in the succession and character of particular beds. But the limited extent to which these strata are exposed at the surface is not merely owing to their former denudation, but even in a still greater degree to their having been largely covered by the New Red Sandstone, as in Cheshire and the midland counties, and here and there by the Permian strata, as in Durham.

It has long been the opinion of the most eminent geologists that the coal-fields of Yorkshire and Lancashire were once united, the overlying upper Coal-measures, Millstone Grit, and Yoredale rocks having been subsequently removed; but what is remarkable is the ancient date now assigned to this denudation, for it seems that a thickness of no less than 10,000 feet of the coal-measures had been carried away before the deposition even of the lower Permian rocks which were thrown down upon the already disturbed truncated edges of the coal-strata.[1] The carboniferous strata most productive of workable coal have so often a basin-shaped arrangement that these troughs have sometimes been supposed to be connected with the original conformation of the surface upon which the beds were deposited. But this structure is really owing to movements of upheaval and subsidence in the earth's crust, and the flexure and inclination of the beds has no connection with the original geographical configuration of the district.

COAL-MEASURES.

I shall now treat more particularly of the productive coal-measures and their mode of origin and organic remains.

Coal formed on land.—In South Wales, already alluded to, where the coal-measures attain a thickness of 10,000 feet, the sandstones and shales throughout appear to have been formed in water of moderate depth, during a slow, but perhaps intermittent, depression of the surface, in a region to which rivers were bringing a never-failing supply of muddy sediment and sand. The same area was alternately covered with vast forests, such as we see in the deltas of great rivers in warm climates, which are liable to be submerged beneath fresh or salt water should the land sink vertically a few feet.

In one section near Swansea, in South Wales, where the total thickness of the coal-measures is 3,246 feet, we learn from Sir H. De la Beche that there are ten principal masses of sandstone. One of these is 500 feet thick, and the whole of them make together a thickness of 2,125 feet. They are separated by masses of shale, varying in thickness from 10 to 50 feet. The intercalated coal-beds, sixteen in number, are generally from 1 to 5 feet thick, one of them, which has two or three layers of clay interposed, attaining 9 feet. At other points in the same coal-field the shales predominate over the sandstones. Great as is the diversity in the horizontal extent of individual coal-seams they all present one characteristic feature, in having, each of

[1] Edward Hull, Quart. Geol. Journ., vol. xxiv. p. 327.

them, what is called its *underclay*. These underclays, co-extensive with every layer of coal, consist of arenaceous shale, sometimes called fire-clay, because it can be made into bricks which stand a furnace heat. They vary in thickness from 6 inches to more than 10 feet; and Sir William Logan first announced in 1841 that they were regarded by the colliers in South Wales as an essential accompaniment of each of the eighty or more seams of coal met with in their coal-field. They are said to form the *floor* on which the coal rests; and some of them have a slight admixture of carbonaceous matter, while others are quite blackened by it.

All of them, as Sir William Logan pointed out, are characterised by enclosing a peculiar species of fossil plant called *Stigmaria*, to the exclusion of other plants. It was also observed that, while in the overlying shales or 'roof' of the coal, ferns and trunks of trees abound without any *Stigmariæ*, and are flattened and compressed, those singular plants of the underclay most commonly retain their natural forms, unflattened and branching freely, sending out their slender rootlets, formerly thought to be leaves, through the mud in all directions. Several species of *Stigmaria* had long been known to botanists, and described by them, before their position under each seam of coal was pointed out, and before their true nature as the roots of trees (some having been actually found attached to the base of *Sigillaria* stumps) was recognised. It was conjectured that they might be aquatic, perhaps floating plants, which sometimes extended their branches and leaves freely in fluid mud, in which they were finally enveloped.

Now that all agree that these underclays are ancient soils, it follows that in every instance where we find them they attest the terrestrial nature of the plants which formed the overlying coal, which consists of the trunks, branches, and leaves of the same plants. The trunks have generally fallen prostrate in the coal, but some of them still remain at right angles to the ancient soils (see fig. 443, p. 402). Professor Göppert, after examining the fossil plants of the coal-fields of Germany, has detected, in beds of pure coal, remains of every family hitherto known to occur fossil in the carboniferous rocks. Many seams, he remarks, are rich in *Sigillariæ*, *Lepidodendra*, and *Stigmariæ*, the latter in such abundance as to appear to form the bulk of the coal. In some places, almost all the plants were calamites, in others ferns.[2]

Between the years 1837 and 1840, six fossil trees were discovered in the coal-field of Lancashire, where it is intersected

[2] Quart. Geol. Journ., vol. v., Mem. p. 17.

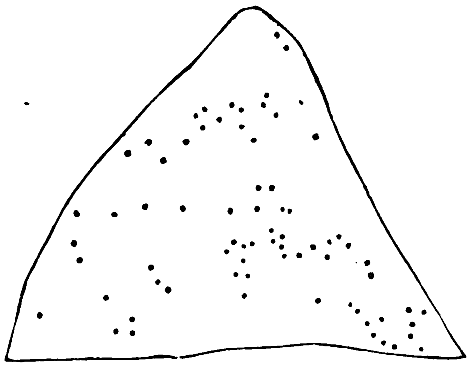
by the Bolton Railway. They were all at right angles to the plane of the bed, which dips about 15° to the south. The distance between the first and the last was more than 100 feet, and the roots of all were embedded in a soft argillaceous shale. In the same plane with the roots is a bed of coal, eight or ten inches thick, which has been found to extend across the railway, or to the distance of at least ten yards. Just above the covering of the roots, yet beneath the coal-seam, so large a quantity of the *Lepidostrobus variabilis* was discovered enclosed in nodules of hard clay, that more than a bushel was collected from the small openings around the base of some of the trees (see figure of this genus, p. 417). The exterior trunk of each was marked by a coating of friable coal, varying from one quarter to three-quarters of an inch in thickness; but it crumbled away on removing the matrix. The dimensions of one of the trees is 15½ feet in circumference at the base, 7½ feet at the top, its height being 11 feet. All the trees have large spreading roots, solid and strong, sometimes branching, and traced to a distance of several feet, and presumed to extend much farther.

In a colliery near Newcastle a great number of *Sigillariæ* occur in the rock as if they had retained the position in which they grew. Not less than thirty, some of them 4 or 5 feet in diameter, were visible within an area of 50 yards square, the interior being sandstone, and the bark having been converted into coal. Such vertical stems are familiar to our coal miners, under the name of 'coal-pipes' and 'bell-moulds.' They are much dreaded, for almost every year in the Bristol, Newcastle, and other coal-fields, they are the cause of fatal accidents. Each cylindrical cast of a tree, formed of solid sandstone, and increasing gradually in size towards the base, and being without branches, has its whole weight thrown downwards, and receives no support from the coating of friable coal which has replaced the bark. As soon, therefore, as the cohesion of this external layer is overcome, the heavy column falls suddenly in a perpendicular or oblique direction from the roof of the gallery whence coal has been extracted, wounding or killing the workman who stands below. It is strange to reflect how many thousands of these trees fell originally in their native forests in obedience to the law of gravity; and how the few which continued to stand erect, obeying, after myriads of ages, the same force, are cast down to immolate their human victims.

It has been remarked that if, instead of working in the dark, the miner was accustomed to remove the upper covering of rock from each seam of coal, and to expose to the day the soils

on which ancient forests grew, the evidence of their former growth would be obvious. Thus in South Staffordshire a seam of coal was laid bare in the year 1844, in what is called an open work at Parkfield Colliery, near Wolverhampton. In the space of about a quarter of an acre the stumps of no less than seventy-three trees with their roots attached appeared, as shown in the

Fig. 432.



Ground plan of a fossil forest, Parkfield Colliery, near Wolverhampton, showing the position of 73 trees in a quarter of an acre.

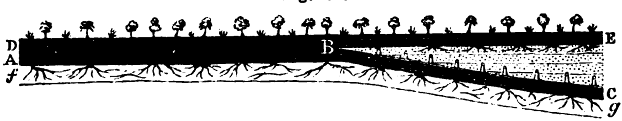
annexed plan (fig. 432), some of them more than 8 feet in circumference. The trunks, broken off close to the root, were lying prostrate in every direction, often crossing each other. One of them measured 15, another 30 feet in length, and others less. They were invariably flattened to the thickness of one or two inches, and converted into coal. Their roots formed part of a stratum of coal 10 inches thick, which rested on a layer of clay 2 inches thick, below which was a second forest, resting on a 2-foot seam of coal. Five feet below this again was a third forest with large stumps of *Lepidodendra*, *Calamites*, and other trees.

Blending of coal-seams.—Both in England and North America seams of coal are occasionally observed to be parted from each other by layers of clay, sand, and shale, and after they have been persistent for miles to come together and blend in one single bed, which is then found to be equal in the aggregate to the thickness of the several seams. I was shown by Mr. H. D. Rogers a remarkable example of this in Pennsylvania. In the Shark Mountain, near Pottsville, in that State, there are thirteen seams of anthracite coal, some of them more than six feet thick, separated by beds of white quartzose grit and a conglomerate of quartz pebbles, often of the size of a hen's egg.

Between Pottsville and the Lehigh Summit Mine, seven of these seams of coal, at first widely separated, are, in the course of several miles, brought nearer and nearer together by the gradual thinning out of the intervening coarse-grained strata and their accompanying shales, until at length they successively unite and form one mass of coal between forty and fifty feet thick, very pure on the whole, though with a few thin partings of clay. This mass of coal I saw quarried in the open air at Mauch Chunk, or the Bear Mountain. The origin of such a vast thickness of vegetable remains so unmixed on the whole with earthy ingredients, can be accounted for in no other way than by the growth, during thousands of years, of trees and ferns, in the manner of peat—a theory which the presence of the Stigmaria *in situ* under each of the seven layers of anthracite fully bears out. The rival hypothesis, of the drifting of plants into a sea or estuary, leaves the non-intermixture of sediment, or of clay, sand, and pebbles with the pure coal, wholly unexplained.

The late Mr. Bowman was the first who gave a satisfactory explanation of the manner in which distinct coal-seams, after maintaining their independence for miles, may at length unite, and then persist throughout another wide area with a thickness equal to that which the separate seams had previously maintained.

Fig. 433.



Uniting of distinct coal-seams.

Let A C be a 3-foot seam of coal originally laid down as a mass of vegetable matter on the level area of an extensive swamp, having an underclay *f g* through which the Stigmariæ or roots of the trees penetrate as usual. One portion B C of this seam of coal is now inclined; the area of the swamp having subsided as much as 25 feet at E C, and become for a time submerged under salt, fresh, or brackish water. Some of the trees of the original forest A B C fell down, others continued to stand erect in the new lagoon, their stumps and part of their trunks becoming gradually enveloped in layers of sand and mud, which at length filled up the new piece of water C E.

When this lagoon has been entirely silted up and converted into land, the forest-covered surface A B will extend once more over the whole area A B E, and a second mass of vegetable matter

D E forming three feet more of coal will accumulate. We then find in the region E C two seams of coal, each three feet thick, with their respective underclays, with erect buried trees based upon the surface of the lower coal, the two seams being separated by 25 feet of intervening shale and sandstone. Whereas in the region A B, where the growth of the forest has never been interrupted by submergence, there will simply be one seam two yards thick corresponding to the united thickness of the beds B E and B C. It may be objected that the uninterrupted growth of plants during the interval of time required for the filling up of the lagoon will have caused the vegetable matter in the region D A B to be thicker than the two distinct seams E and C, and no doubt there would actually be a slight excess representing one or more generation of trees and plants forming the undergrowth; but this excess of vegetable matter when compressed into coal would be so insignificant in thickness that the miner might still affirm that the seam D A throughout the area D A B was equal to the two seams C and E.

Cause of the purity of coal.—The purity of the coal itself, or the absence in it of earthy particles and sand, throughout areas of vast extent, is a fact which appears very difficult to explain when we attribute each coal-seam to a vegetation growing in swamps. It has been asked how, during river inundations capable of sweeping away the leaves of ferns and the stems and roots of *Sigillariæ* and other trees, could the waters fail to transport some fine mud into the swamps? One generation after another of tall trees grew with their roots in mud, and their leaves and prostrate trunks formed layers of vegetable matter, which was afterwards covered with mud since turned to shale. Yet the coal itself, or altered vegetable matter, remained all the while unsoiled by earthy particles. This enigma, however perplexing at first sight, may, I think, be solved by attending to what is now taking place in deltas. The dense growth of reeds and herbage which encompasses the margins of forest-covered swamps in the valley and delta of the Mississippi is such that the fluviatile waters, in passing through them, are filtered and made to clear themselves entirely before they reach the areas in which vegetable matter may accumulate for centuries, forming coal if the climate be favourable. There is no possibility of the least intermixture of earthy matter in such cases. Thus in the large submerged tract called the 'Sunk Country,' near New Madrid, forming part of the western side of the valley of the Mississippi, erect trees have been standing ever since the year 1811-12, killed by the great earthquake of that date; lacustrine and swamp plants have been growing

there in the shallows, and several rivers have annually inundated the whole space, and yet have been unable to carry in any sediment within the outer boundaries of the morass, so dense is the marginal belt of reeds and brushwood. It may be affirmed that generally in the 'cypress swamps' of the Mississippi no sediment mingles with the vegetable matter accumulated there from the decay of trees and semi-aquatic plants. As a singular proof of this fact, I may mention that whenever any part of a swamp in Louisiana is dried up, during an unusually hot season, and the wood set on fire, pits are burnt into the ground many feet deep, or as far down as the fire can descend, without meeting with water, and it is then found that scarcely any residuum or earthy matter is left. At the bottom of all these 'cypress swamps' a bed of clay is found, with roots of the tall cyprus (*Taxodium distichum*), just as the underclays of the coal are filled with *Stigmaria.*

Conversion of bituminous coal into anthracite.—It appears from the researches of Liebig and other eminent chemists, that when wood and vegetable matter are buried in the earth exposed to moisture, and partially or entirely excluded from the air, they decompose slowly and evolve carbonic acid gas, thus parting with a portion of their original oxygen. By this means, they become gradually converted into lignite or wood-coal, which contains a larger proportion of hydrogen than wood does. A continuance of decomposition changes this lignite into common or bituminous coal, chiefly by the discharge of carburetted hydrogen, or the gas by which we illuminate our streets and houses. According to Bischoff, the inflammable gases which are always escaping from mineral coal, and are so often the cause of fatal accidents in mines, always contain carbonic acid, carburetted hydrogen, nitrogen, and olefiant gas. The disengagement of all these gradually transforms ordinary or bituminous coal into anthracite, to which the various names of glance-coal, coke, hard-coal, culm, and many others, have been given.

There is an intimate connection between the extent to which the coal has in different regions parted with its gaseous contents, and the amount of disturbance which the strata have undergone. The coincidence of these phenomena may be attributed partly to the greater facility afforded for the escape of volatile matter, when the fracturing of the rocks has produced an infinite number of cracks and crevices. The gases and water which are made to penetrate these cracks are probably rendered the more effective as metamorphic agents by increased temperature derived from the interior. It is well known that, at the present period, thermal waters and hot vapours burst out from the

earth during earthquakes, and these would not fail to promote the disengagement of volatile matter from the carboniferous rocks.

In Pennsylvania the strata of coal are horizontal to the westward of the Alleghany Mountains, where the late Professor H. D. Rogers pointed out that they were most bituminous; but as we travel south-eastward, where they no longer remain level and unbroken, the same seams become progressively debitumenised in proportion as the rocks become more bent and distorted. At first on the Ohio river the proportion of hydrogen, oxygen, and other volatile matters ranges from forty to fifty per cent. Eastward of this line, on the Monongahela, it still approaches forty per cent., where the strata begin to experience some gentle flexures. On entering the Alleghany Mountains, where the distinct anticlinal axes begin to show themselves, but before the dislocations are considerable, the volatile matter is generally in the proportion of eighteen or twenty per cent. At length, when we arrive at some insulated coal-fields associated with the boldest flexures of the Appalachian chain, where the strata have been actually turned over, as near Pottsville, we find the coal to contain only from six per cent. of volatile matter, thus becoming a genuine anthracite.

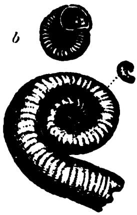
Clay-ironstone.—Bands and nodules of clay-ironstone are common in the coal-measures, and are formed, says Sir H. De la Beche, of carbonate of iron mingled mechanically with earthy matter, like that constituting the shales. Mr. Robert Hunt, of the Museum of Practical Geology, instituted a series of experiments to illustrate the production of this substance, and found that decomposing vegetable matter, such as would be distributed through all coal strata, prevented the farther oxidation of the proto-salts of iron, and converted the peroxide into protoxide by taking a portion of its oxygen to form carbonic acid. Such carbonic acid, meeting with the protoxide of iron in solution, would unite with it and form a carbonate of iron; and this mingling with fine mud, when the excess of carbonic acid was removed, might form beds or nodules of argillaceous ironstone.[3]

Intercalated marine beds in coal-measures.—In the coal-fields both of Europe and America the association of fresh, brackish-water, and marine strata with coal-seams of terrestrial origin is frequently recognised. Thus, for example, a deposit near Shrewsbury, probably formed in brackish water, has been described by Sir R. Murchison as the youngest member of the

[3] Memoirs of Geol. Survey, vol. i. part i. pp. 51, 255, &c.

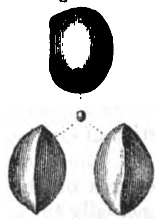
coal-measures of that district, at the point where they are in contact with the overlying Permian group. It consists of shales and sandstones about 150 feet thick, with coal and traces of plants; including a bed of limestone varying from 2 to 9 feet in thickness, which is cellular, and resembles some lacustrine limestones of France and Germany. It has been traced for 30 miles in a straight line, and can be recognised at still more distant points. The characteristic fossils are a small bivalve, having the form of a *Cyclas* or *Cyrena*, also a small entomostracan, *Leperditia inflata* (fig. 435), and the small shell of a minute tubercular annelid

Fig. 434.



a. Microconchus (Spirorbis) carbonarius, Murch.
Nat. size and magnified.
b. Variety of same.

Fig. 435.



Leperditia inflata.
Nat. size and magnified.
Murchison.

of an extinct genus called *Microconchus* (fig. 434) allied to *Spirorbis.* In many coal-fields there are freshwater strata, some of which contain shells termed *Anthracosia* and *Anthracomya*, and referred to the family *Unionidæ*; but in the midst of the coal series in Yorkshire there is one thin but very widely spread

Fig. 436.

Goniatites Listeri, Martin, ⅔. Coal-measures, Yorkshire and Lancashire.

Fig. 437.

Aviculopecten papyraceus, Goldf., ½. (*Pecten papyraceus*, Sow.)

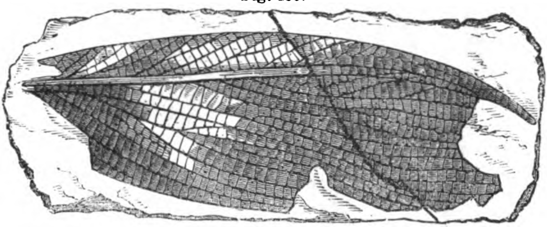
stratum, abounding in fishes and marine shells, such as *Goniatites Listeri* (fig. 436), *Orthoceras*, and *Aviculopecten papyraceus*, Goldf. (fig. 437).

Insects in European coal.—Articulate animals of the genus Scorpion were found by Count Sternberg in 1835 in the coal-

measures of Bohemia, and about the same time in those of Coalbrook Dale by Mr. Prestwich, where also true insects such as beetles of the family *Curculionidæ*, a neuropterous insect of the genus *Corydalis*, and another related to the *Phasmidæ*, have been found.

From the coal of Wetting in Westphalia several specimens of the cockroach or *Blatta* family, and the wing of a cricket (*Acridites*), have been described by Germar. Professor Goldenberg published, in 1854, descriptions of no less than twelve species of insects from the nodular clay-ironstone of Saarbrück, near Trèves.[4] Among them are several *Blattinæ*, three species of *Neuroptera*, one beetle of the *Scarabæus* family, a grasshopper or locust, *Gryllacris* (see fig. 438), and several white ants or

Fig. 438.



Wing of a Grasshopper, *Gryllacris lithanthraca*, Goldenberg, nat. size. Coal, Saarbrück, near Trèves.

Termites. Professor Goldenberg showed me, in 1864, the wing of a white ant, found low down in the productive coal-measures of Saarbrück, in the interior of a flattened Lepidodendron. It is much larger than that of any known living species of the same genus.

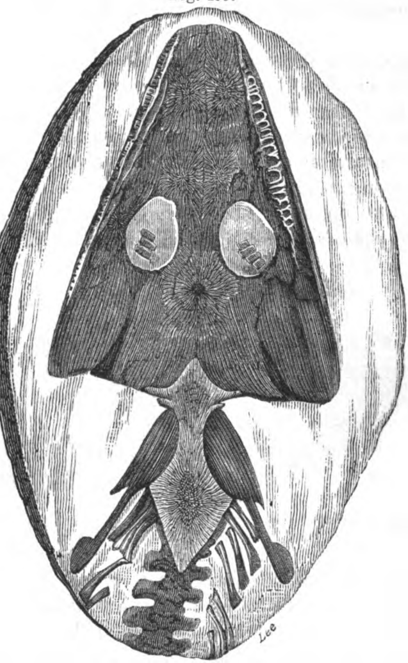
Carboniferous amphibia—Labyrinthodonts.—No vertebrated animals more highly organised than fishes were known to occur in rocks of higher antiquity than the Permian until the year 1843, when the *Apateon pedestris*, Meyer, was discovered in the coal-measures of Münster-Appel in Rhenish Bavaria.

Four years later, in 1847, Professor Von Dechen found remains of other species of Amphibia in the Saarbrück coal-field above alluded to. These were described by the late Professor Goldfuss under the generic name of *Archegosaurus*, but we owe our full and accurate knowledge of their structure to the investigations of Von Meyer. The annexed drawing shows the skull, thoracic plate, scapulæ, vertebræ, and ribs of *Archego-*

4 Palæont. Dunker and V. Meyer, vol. iv. p. 17.

saurus Decheni. Among the more remarkable features of *Archegosaurus* are, firstly, the complete protection of the upper

Fig. 439.



Archegosaurus minor, Goldfuss. Fossil reptile from the coal-measures, Saarbrück.

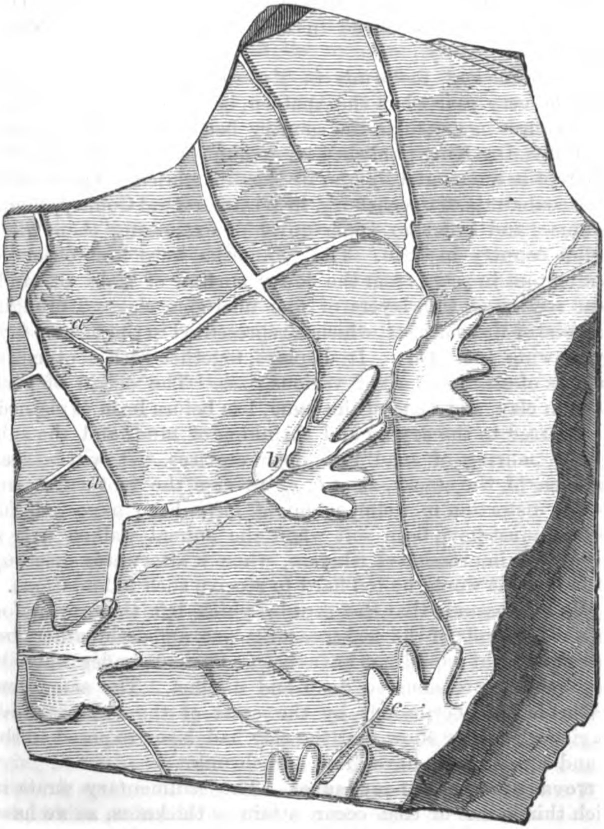
surface of the skull by bony plates, which fit accurately together at all stages of growth ; secondly, the thoracic shield, consisting of three bony plates, of which the two outer overlap the central one ; thirdly the ventral armour, composed of numerous imbricated bony scutes (fig. 440) disposed diagonally upon the under surface, between the fore and hind limbs. The teeth resemble those of *Mastodonsaurus* (p. 359), but the folding of the dentinal wall is less complex. Unlike its nearest allies, *Archegosaurus* retained throughout life imperfectly ossified or Notochordal vertebræ. The total length of a large individual may have been about seven feet.

Fig. 440.

Imbricated covering of skin of *Archegosaurus medius*, Goldf. Magnified.

Some of the peculiarities of *Archegosaurus* suggest a comparison with *Crocodilia*, but its true affinity is with the Amphibia. It may be included, together with the Triassic Labyrinthodon and some Carboniferous genera to be mentioned im-

Fig. 441.



Scale one-sixth the original.

Slab of sandstone from the coal-measures of Pennsylvania, with footprints air-breathing reptile and casts of cracks.

mediately in the order Labyrinthodonta, a group co-ordinate with the recent orders, Batrachia (leaping Amphibia), Urodela (tailed Amphibia), and Gymnophiona (snake-like Amphibia), and most nearly connected with the two latter.

Since the first discovery of Carboniferous Labyrinthodonts in Germany, many additional genera and species have been brought to light. There are now established, according to Mr. Miall, at least seventeen genera, most of which have occurred in the British Isles, particularly in the coal-fields of Edinburgh, Glasgow, Northumberland, Kilkenny, and Staffordshire. One example has been discovered in the Yoredale Rocks of North Yorkshire.[5]

Labyrinthodont footprints in American coal-measures.—In 1844, the very year when the Apateon, before mentioned, of the coal was first met with in the country between the Moselle and the Rhine, Dr. King published an account of the footprints of a large reptile discovered by him in North America. These occur in the coal-strata of Greensburg, in Westmoreland County, Pennsylvania; and I had an opportunity of examining them when in that country in 1846. The footmarks were first observed standing out in relief from the lower surface of slabs of sandstone, resting on thin layers of fine unctuous clay. I brought away one of these masses, which is represented in the accompanying drawing (fig. 441). It displays, together with footprints, the casts of cracks (*a*, *a′*) of various sizes. The origin of such cracks in clay, and casts of the same, has before been explained, and referred to the drying and shrinking of mud, and the subsequent pouring of sand into open crevices. It will be seen that some of the cracks, as at *b*, *c*, traverse the footprints, and produce distortion in them, as might have been expected, for the mud must have been soft when the animal walked over it and left the impressions; whereas, when it afterwards dried up and shrank, it would be too hard to receive such indentations.

We may assume that the reptile which left these prints on the ancient sands of the coal-measures was an air-breather, because its weight would not have been sufficient under water to have made impressions so deep and distinct. The same conclusion is also borne out by the casts of the cracks above described, for they show that the clay had been exposed to the air and sun, so as to have dried and shrunk.

Nova Scotia coal-measures.—The sedimentary strata in which thin seams of coal occur, attain a thickness, as we have seen, of 18,000 feet in the North of England exclusive of the Mountain Limestone, and are estimated by Von Dechen at over 20,000 feet in Rhenish Prussia. But the finest example in the world of a natural exposure in a continuous section ten miles long, occurs in the sea-cliffs bordering a branch of the Bay of Fundy in Nova Scotia. These cliffs, called the 'South Joggins,

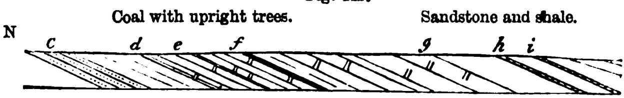
[5] L. C. Miall, Report on Labyrinthodonta, Brit. Assoc. Bradford, 1873.

which I first examined in 1842, and afterwards with Dr. Dawson in 1845, have lately been admirably described by the last-mentioned geologist[6] in detail, and his evidence is most valuable as showing how large a portion of this dense mass was formed on land, or in swamps where terrestrial vegetation flourished, or in freshwater lagoons. His computation of the thickness of the whole series of carboniferous strata as exceeding three miles, agrees with the measurement made independently by Sir William Logan in his survey of this coast.

There is no reason to believe that in this vast succession of strata, comprising some marine as well as many freshwater and terrestrial formations, there is any repetition of the same beds. There are no faults to mislead the geologist, and cause him to count the same beds over more than once, while some of the same plants have been traced from the top to the bottom of the whole series, and are distinct from the flora of the antecedent Devonian formation of Canada. Eighty-one seams of coal, varying in thickness from an inch to about five feet, have been discovered, and no less than seventy-one of these have been actually exposed in the sea-cliffs.

In the annexed section (fig. 442), which I examined in 1842,

Fig. 442.



Section of the cliffs of the South Joggins, near Minudie, Nova Scotia.

c. Grindstone. *d, g*. Alternations of sandstone, shale, and coal containing upright trees. *e, f*. Portion of cliff, given on a larger scale in fig. 443. *f*. 4-foot coal, main seam. *h, i*. Shale with freshwater mussels, see p. 411.

the beds from *c* to *i* are seen all dipping the same way, their average inclination being at an angle of 24° S.S.W. The vertical height of the cliffs is from 150 to 200 feet; and between *d* and *g*—in which space I observed seventeen trees in an upright position, or, to speak more correctly, at right angles to the planes of stratification—I counted nineteen seams of coal, varying in thickness from 2 inches to 4 feet. At low tide a fine horizontal section of the same beds is exposed to view on the beach, which at low tide extends sometimes 200 yards from the base of the cliff. The thickness of the beds alluded to, between *d* and *g*, is about 2,500 feet, the erect trees consisting chiefly of large *Sigillariæ*, occurring at ten distinct levels, one above the other. The usual height of the buried trees seen by me was from 6 to 8 feet; but one trunk was about 25 feet high and 4 feet in diameter, with a considerable bulge at the base. In

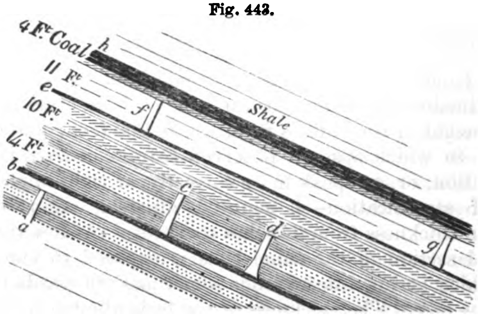
[6] Acadian Geology, 2nd edit. 1868.

no instance could I detect any trunk intersecting a layer of coal, however thin; and most of the trees terminated downwards in seams of coal. Some few only were based on clay and shale; none of them, except *Calamites*, on sandstone. The erect trees, therefore, appeared in general to have grown on beds of vegetable matter. In the underclays *Stigmaria* abounds.

These root-bearing beds have been found under all the coal-seams, and such old soils are at present the most destructible masses in the whole cliff, the sandstones and laminated shales being harder and more capable of resisting the action of the waves and the weather. Originally the reverse was doubtless true, for in the existing delta of the Mississippi those clays in which the innumerable roots of the deciduous cypress and other swamp trees ramify in all directions are seen to withstand far more effectually the undermining power of the river, or of the sea at the base of the delta, than do beds of loose sand or layers of mud not supporting trees. It is obvious that if this sand or mud be afterwards consolidated and turned to sandstone and hard shale, it would be the least destructible.

In regard to the plants, they belong to the same genera, and most of them to the same species, as those met with in the distant coal-fields of Europe. Dr. Dawson has enumerated more than 150 species, two-thirds of which are European, a greater agreement than can be said to exist between the same Nova Scotia flora and that of the coal-fields of the United States. By referring to the section, fig. 442, the position of

Fig. 443.



Erect fossil trees. Coal-measures, Nova Scotia.

the four-foot coal will be perceived, and in fig. 443 (a section made by me in 1842 of a small portion) that from *e* to *f* of the same cliff is exhibited, in order to show the manner of occurrence of erect fossil trees at right angles to the planes of the inclined strata.

In the sandstone, which filled their interiors, I frequently observed fern-leaves, and sometimes fragments of *Stigmaria*, which had evidently entered together with sediment after the trunk had decayed and become hollow, and while it was still standing under water. Thus the tree, *a*, fig. 443, represented in the bed *e* in the section, fig. 442, is a hollow trunk 5 feet 8 inches in length, traversing several strata, and cut off at the top by a layer of clay 2 feet thick, on which rests a seam of coal (*b*, fig. 443) 1 foot thick. On this coal again stood two large trees (*c* and *d*), while at a greater height the trees *f* and *g* rest upon a thin seam of coal (*e*), and above them is an underclay, supporting the 4-foot coal.

Occasionally the layers of matter in the inside of the tree are more numerous than those without; but it is more common in the coal-measures of all countries to find a cylinder of pure sandstone—the cast of the interior of a tree—intersecting a great many alternating beds of shale and sandstone, which originally enveloped the trunk as it stood erect in the water. Such a want of correspondence in the materials outside and inside, is just what we might expect if we reflect on the difference of time at which the deposition of sediment will take place in the two cases; the embedding of the tree having gone on for many years before its decay had made much progress. In many places distinct proof is seen that the enveloping strata took years to accumulate, for some of the sandstones surrounding erect sigillarian trunks support at different levels roots and stems of *Calamites*; the *Calamites* having begun to grow after the older *Sigillariæ* had been partially buried.

The general absence of structure in the interior of the large fossil trees of the Coal implies the very durable nature of their bark, as compared with their woody portion. The same difference of durability of bark and wood exists in modern trees, and was first pointed out to me by Dr. Dawson, in the forests of Nova Scotia, where the Canoe Birch (*Betula papyracea*) has such tough bark that it may sometimes be seen in the swamps looking externally sound and fresh, although consisting simply of a hollow cylinder with all the wood decayed and gone. When portions of such trunks have become submerged in the swamps they are sometimes found filled with mud. One of the erect fossil trees of the South Joggins 15 feet in height, occurring at a higher level than the main coal, has been shown by Dr. Dawson to have a coniferous structure, so that some *Coniferæ* of the Coal period grew in the same swamps as *Sigillariæ*, just as now the deciduous Cypress (*Taxodium distichum*) abounds in the marshes of Louisiana even to the edge of the sea.

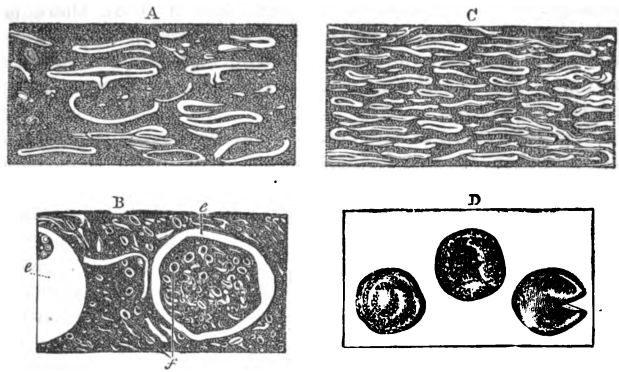
When the carboniferous forests sank below high-water mark, a species of *Spirorbis* or *Serpula* (fig. 434, p. 396), attached itself to the outside of the stumps and stems of the erect trees, adhering occasionally even to the interior of the bark—another proof that the process of envelopment was very gradual. These hollow upright trees, covered with innumerable marine annelids, reminded me of a 'cane-brake,' as it is commonly called, consisting of tall reeds, *Arundinaria macrosperma*, which I saw in 1846, at the Balize, or extremity of the delta of the Mississippi. Although these reeds are freshwater plants, they were covered with barnacles, having been killed by an incursion of salt water over an extent of many acres, where the sea had for a season usurped a space previously gained from it by the river. Yet the dead reeds, in spite of this change, remained standing in the soft mud, enabling us to conceive how easily the larger *Sigillariæ*, hollow as they were but supported by strong roots, may have resisted an incursion of the sea.

The high tides of the Bay of Fundy, rising more than 60 feet, are so destructive as to undermine and sweep away continually the whole face of the cliffs, and thus a new crop of erect fossil trees is brought into view every three or four years. They are known to extend over a space between two or three miles from north to south, and more than twice that distance from east to west, being seen in the banks of streams intersecting the coal-field.

Structure of Coal.—The bituminous coal of Nova Scotia is similar in composition and structure to that of Great Britain, being chiefly derived from Sigillaroid trees mixed with leaves of ferns and of a Lycopodiaceous tree called *Cordaites* (*Noeggerathia*, &c., for genus see fig. 431, p. 383), supposed by Dawson to have been deciduous, and which had broad parallel veined leaves without a mid-rib. On the surface of the seams of coal are large quantities of mineral charcoal, which doubtless consist, as Dr. Dawson suggests, of fragments of wood which decayed in the open air, as would naturally be expected in swamps where so many erect trees were preserved. Beds of cannel-coal display, says Dr. Dawson, such a microscopical structure and chemical composition as shows them to have been of the nature of fine vegetable mud such as accumulates in the shallow ponds of modern swamps. It appears that in these cannel-coals the spore-cases of Lepidodendra are often more abundant than in the ordinary coal. Professor Huxley has ascertained that in the Better-Bed coal of Lowmoor (see A B, fig. 444) the spores and sporangia constitute a very large mass of the deposit, and this is also the case with the recent 'White

Coal' of Australia (c, fig. 448).[7] Professor Morris in 1836 affirmed that these bodies were the spore-cases of a plant allied to the living club-mosses, and Mr. Carruthers a few years ago

Fig. 444.



A. '*Better Bed*' Coal, from a portion unusually full of *Sporangia*, which are here shown in transverse section.
B. Same coal, section parallel with bedding; showing *Sporangia*, *e*, and spores, *f*; the latter (which are here represented somewhat too large) appear as bright rings enclosing a dark spot.
C. Australian 'White Coal,' showing *Sporangia* in transverse section.
D. External view of *Sporangia* separated from the 'White Coal.'

All these figures are enlarged about 16 diameters.

The bodies here called *Sporangia* are by some persons considered to be *Macrospores*; and those called *Spores*, to be *Microspores*.

confirmed this opinion by finding the discoidal sacs adhering to the leaves of the fossilised cone which produced them. He named the plant *Flemingites gracilis* because Professor Fleming had previously pointed out similar bodies in the coal of Scotland. Professor Huxley is inclined to believe that the English coal is largely composed of these bodies, but Principal Dawson, who has made a careful examination of the 81 coal-seams in Nova Scotia both *in situ* and in specimens under the microscope, states that 'he could only recognise the bodies called by him Sporangites in sixteen seams, and of these only four had the rounded Lycopodiaceous spore-cases similar to those of Flemingites.' He maintains, therefore, that Sporangite beds are exceptional among coals, and that cortical and woody matters are the most abundant ingredients in all the ordinary kinds and he does not think that the coals of England are likely to prove an exception.[8] The underclays are loamy soils, which

[7] Huxley, Contemporary Review, 1870; and Critiques and Addresses, p. 92.

[8] Dawson, Spore-cases in Coal, Silliman's Journ. of Science, 1871 p. 261.

must have been sufficiently above water to admit of drainage, and the absence of sulphurates, and the occurrence of carbonate of iron in them, prove that when they existed as soils, rain-water, and not sea-water percolated them. With the exception, perhaps, of *Asterophyllites* (see fig. 465, p. 418), there is a remarkable absence from the coal-measures of any form of vegetation properly aquatic, the true coal being a sub-aërial accumulation in soil that was wet and swampy but not permanently submerged.

Air-breathers of the coal.—If we have rightly interpreted the evidence of the former existence at more than eighty different levels of forests of trees, some of them of vast extent, and which lasted for ages, giving rise to a great accumulation of vegetable matter, it is natural to ask whether there were not many air-breathing inhabitants of these same regions. As yet no remains of mammalia or birds have been found, a negative character common at present to all the Palæozoic formations, but in 1852 the osseous remains of an amphibian, the first ever met with in the Carboniferous strata of the American continent, were found by Dr. Dawson and myself. We detected them in the interior of one of the erect Sigillariæ before alluded to as of such frequent occurrence in Nova Scotia. The tree was about 2 feet in diameter, and consisted of an external cylinder of bark, converted into coal, and an internal stony axis of black sandstone, or rather mud and sand stained black by carbonaceous matter, and cemented together with fragments of wood into a rock. These fragments were in the state of charcoal, and seem to have fallen to the bottom of the hollow tree while it was rotting away. The skull, jaws, and vertebræ of an amphibian, probably about 2½ feet in length (*Dendrerpeton Acadianum*, Owen), were scattered through this stony matrix. The shell, also, of a *Pupa* (see fig. 446, p. 408), the first land-shell ever met with in the coal, or in beds older than the tertiary, was observed in the same stony mass. Dr. Wyman of Boston pronounced the reptile to be allied in structure to *Monobranchus* and *Menopoma*, species of amphibians now inhabiting the North American rivers. The same view was afterwards confirmed by Professor Owen, who also pointed out the resemblance of the cranial plates to those seen in the skull of *Archegosaurus* and *Labyrinthodon.*[9] Whether the creature had crept into the hollow tree while its top was still open to the air, or whether it was washed in with mud during a flood, or in whatever other manner it entered, must be matter of conjecture.

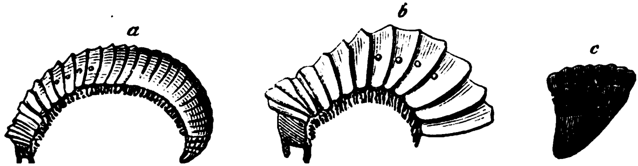
[9] Geol. Quart. Journ., vol. ix. p. 58.

Footprints of two reptiles of different sizes had previously been observed by Dr. Harding and Dr. Gesner on ripple-marked flags of the lower coal-measures of Nova Scotia (No. 2, fig. 451, p. 411), evidently made by quadrupeds walking on the ancient beach, or out of the water, just as the recent Menopoma is sometimes observed to do.

The remains of a second and smaller species of Dendrerpeton, *D. Oweni*, were also found accompanying the larger one, and still retaining some of its dermal appendages; and in the same tree were the bones of a third small lizard-like reptile, *Hylonomus Lyelli*, 7 inches long, with stout hind limbs, and fore limbs comparatively slender, supposed by Dr. Dawson to be capable of walking and running on land.[1]

In a second specimen of an erect stump of a hollow tree 15 inches in diameter, the ribbed bark of which showed that it was a Sigillaria, and which belonged to the same forest as the specimen examined by us in 1852, Dr. Dawson obtained not only fifty specimens of *Pupa vetusta* (fig. 446), and nine skeletons of reptiles belonging to four species, but also several examples of an articulated animal resembling the recent centipede or gally worm, a creature which feeds on decayed vegetable matter (see fig. 445). Under the microscope, the head, with the eyes, mandible, and labrum are well seen. It is interesting, as being the earliest known representative of the myriapods, none of which had previously been met with in rocks older than the oolite or lithographic slate of Germany.

Fig. 445.



Xylobius Sigillariæ, Dawson. Coal, Nova Scotia and Great Britain.
a. Natural size. *b*. Anterior part, magnified. *c*. Caudal extremity, magnified.

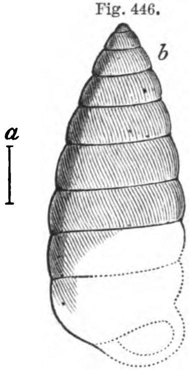
Some years after the discovery of the first Pupa, Dr. Dawson, carefully examining the same great section containing so many buried forests in the cliffs of Nova Scotia, discovered another bed, separated from the tree containing Dendrerpeton by a mass of strata more than 1,200 feet thick. As there were 21 seams of coal in this intervening mass, the length of time comprised in the interval is not to be measured by the mere thickness of the sandstones and shales. This lower bed is an under-

[1] Dawson, Air-Breathers of the Coal in Nova Scotia. Montreal, 1863.

clay 7 feet thick, with stigmarian rootlets, and the small land-shells occurring in it are in all stages of growth. They are chiefly confined to a layer about 2 inches thick, and are unmixed with any aquatic shells. They were all originally entire when imbedded, but are most of them now crushed, flattened, and distorted by pressure; they must have been accumulated, says Dr. Dawson, in mud deposited in a pond or creek.

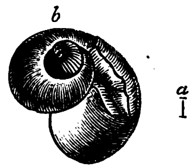
The surface striæ of *Pupa vetusta*, when magnified 50 diameters, present exactly the same appearance as a portion corresponding in size of the common English *Pupa juniperi* (= *P. secale*), and the internal hexagonal cells, magnified 500 diameters, show the internal structure of the fossil and recent Pupa to be identical. In 1866[2] Dr. Dawson discovered in this lower bed, so full of the Pupa, another land-shell of the genus Helix (sub-genus Zonites) (see fig. 447).

Fig. 446.



Pupa vetusta, Dawson.
a. Natural size.

Fig. 447.



Zonites (Conulus) priscus, Carpenter.
b. Magnified.

None of the reptiles obtained from the coal-measures of the South Joggins are of a higher grade than the labyrinthodonts, but some were of very great size, two caudal vertebræ found by Mr. Marsh in 1862 measuring two and a half inches in diameter, and implying a gigantic aquatic amphibian with a powerful swimming tail.

Except some obscure traces of an insect found by Dr. Dawson in a coprolite of a terrestrial reptile occurring in a fossil tree, no specimen of this class has been brought to light in the Joggins. But Mr. James Barnes found in a bed of shale at Little Glace Bay, Cape Breton, the wing of an Ephemera, which must have measured 7 inches from tip to tip of the

[2] Dawson, Acadian Geology, 1868, p. 385.

expanded wings, larger than any known living insect of the Neuropterous family.

That we should have made so little progress in obtaining a knowledge of the terrestrial fauna of the Coal is certainly a mystery; but we have no reason to wonder at the extreme rarity of insects, seeing how few are known in the carboniferous rocks of Europe, worked for centuries before America was discovered, and now quarried on so enormous a scale. These European rocks have not yet produced a single land-shell, in spite of the millions of tons of coal annually extracted, and the many hundreds of soils replete with the fossil roots of trees and the erect trunks and stumps preserved in the position in which they grew. In many large coal-fields we continue as much in the dark respecting the invertebrate air-breathers then living as if the coal had been thrown down in mid-ocean. The early date of the Carboniferous strata cannot explain the enigma, because we know that while the land supported a luxuriant vegetation, the contemporaneous seas swarmed with life—with Articulata, Mollusca, Radiata, and Fishes. The perplexity in which we are involved when we attempt to solve this problem may be owing partly to our want of diligence as collectors, but still more perhaps to ignorance of the laws which govern the fossilisation of land-animals, whether of high or low degree.

Carboniferous rain-prints.—At various levels in the coal

Fig. 448. Fig. 449.

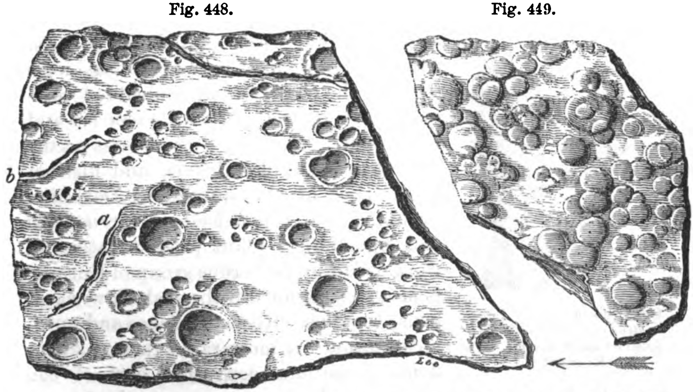


Fig. 448. Carboniferous rain-prints with worm-tracks (*a*, *b*) on green shale, from Cape Breton, Nova Scotia. Natural size.

Fig. 449. Casts of rain-prints on a portion of the same slab (Fig. 448), seen to project on the under side of an incumbent layer of arenaceous shale. Natural size. The arrow represents the supposed direction of the shower.

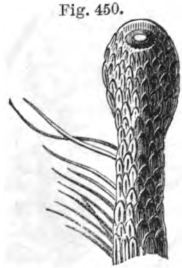
measures of Nova Scotia ripple-marked sandstones, and shales

with rain-prints, were seen by Dr. Dawson and myself, but still more perfect impressions of rain were discovered by Mr. Brown near Sydney in the adjoining island of Cape Breton. They consist of very delicate markings on greenish slates, accompanied by worm-tracks (*a*, *b*, fig. 448) such as are often seen between high and low water mark on the recent mud of the Bay of Fundy.

The great humidity of the climate of the Coal period had been previously inferred from the number of its ferns and the continuity of its forests for hundreds of miles; but it is satisfactory to have at length obtained such positive proofs of showers of rain, the drops of which resembled in their average size those which now fall from the clouds. From such data we may presume that the atmosphere of the Carboniferous period corresponded in density with that now investing the globe, and that different currents of air varied then as now in temperature, so as to give rise, by their mixture, to the condensation of aqueous vapour.

Folding and denudation of the beds indicated by the Nova Scotia coal-strata.—The series of events which are indicated by the great section of the coal-strata in Nova Scotia consist of a gradual and long-continued subsidence of a tract which throughout most of the period was in the state of a delta, though occasionally submerged beneath a sea of moderate depth. Deposits of mud and sand were first carried down into a shallow sea on the low shores of which the foot-prints of reptiles were sometimes impressed (see above, p. 400). Though no regular seams of coal were formed, the characteristic imbedded coal-plants are of the genera *Cyclopteris* and *Alethopteris*, agreeing with species occurring at much higher levels, and distinct from those of the antecedent Devonian group. The *Lepidodendron corrugatum* (see fig. 450), a plant predominating in the Lower Carboniferous group of Europe, is also conspicuous in these shallow-water beds, together with many fishes and entomostracans. A more rapid rate of subsidence sometimes converted part of the sea into deep clear water, in which there was a growth of coral which was afterwards turned into crystalline limestone, and parts of it, apparently by the action of sulphuric acid, into gypsum. In spite of continued sinking, amounting to several thousand feet, the sea might in time have been rendered shallow

Fig. 450.



Cone and branch of *Lepidodendron corrugatum*. Lower Carboniferous, New Brunswick.

by the growth of coral, had not its conversion into land or swampy ground been accelerated by the pouring in of sand and the advance of the delta accompanied with such fluviatile and brackish-water formations as are common in lagoons.

The amount to which the bed of the sea sank down in order to allow of the formation of so vast a thickness of rock of sedimentary and organic origin is expressed by the total thickness of the Carboniferous strata, including the coal-measures, No. 1, and the rocks which underlie them, No. 2, fig. 451.

Fig. 451.

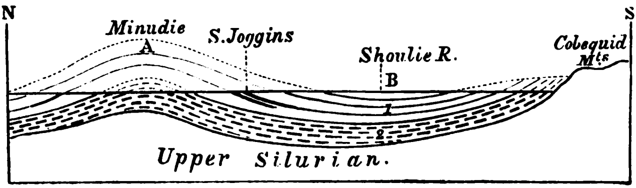


Diagram showing the curvature and supposed denudation of the Carboniferous strata in Nova Scotia.

A. Anticlinal axis of Minudie. B. Synclinal of Shoulie River.
1. Coal-measures. 2. Lower Carboniferous.

After the strata No. 2 had been elaborated, the conditions proper to a great delta exclusively prevailed, the subsidence still continuing so that one forest after another grew and was submerged until their underclays with roots, and usually seams of coal, were left at more than eighty distinct levels. Here and there also deposits bearing testimony to the existence of fresh or brackish-water lagoons, filled with calcareo-bituminous mud, were formed. In these beds (*h* and *i*, fig. 442, p. 401) are found freshwater bivalves or mussels allied to Anodon, though not identical with that or any living genus, and called *Naiadites carbonarius* by Dawson. They are associated with small entomostracous crustaceans of the genus Cythere, and scales of small fishes. Occasionally some of the calamite brakes and forests of Sigillariæ and Coniferæ were exposed in the flood season, or sometimes, perhaps by slight elevatory movements, to the denuding action of the river or the sea.

In order to interpret the great coast section exposed to view on the shores of the Bay of Fundy (fig. 451), the student must in the first place understand that the newest or last-mentioned coal formations would have been the only ones known to us (for they would have covered all the others), had there not been two great movements in opposite directions, the first consisting of a general sinking of three miles, which took place during the Carboniferous period, and the second, an upheaval of more

limited horizontal extent, by which the anticlinal axis A was formed. That the first great change of level was one of subsidence is proved by the fact that there are shallow-water deposits at the base of the Carboniferous series, or in the lowest beds of No. 2.

Subsequent movements produced in the Nova Scotia and the adjoining New Brunswick coal-fields the usual anticlinal and synclinal flexures. In order to follow these we must survey the country for about thirty miles round the South Joggins, or the region where the erect trees described in the foregoing pages are seen. As we pass along the cliffs for miles in a southerly direction, the beds containing these fossil trees, which were mentioned as dipping about 18° south, are less and less inclined until they become nearly horizontal in the valley of a small river called the Shoulie, as ascertained by Dr. Dawson. After passing this synclinal line the beds begin to dip in an opposite or north-easterly direction, acquiring a steep dip where they rest unconformably on the edges of the Upper Silurian strata of the Cobequid Hills, as shown in fig. 451. But if we travel northwards towards Minudie from the region of the coal-seams and buried forests, we find the dip of the coal-strata increasing from an angle of 18° to one of more than 40°, lower beds being continually exposed to view till we reach the anticlinal axis A and see the lower Carboniferous formation, No. 2, at the surface. The rocks removed by denudation are expressed by the faint lines at A; and thus the student will see that, according to the principles laid down in the seventh chapter, we are enabled, by the joint operations of upheaval and denudation, to look, as it were, about three miles into the interior of the earth without passing beyond the limits of a single formation.

CHAPTER XXIV.

FLORA AND FAUNA OF THE CARBONIFEROUS PERIOD.

Vegetation of the Coal period—Ferns, Lycopodiaceæ, Equisetaceæ, Sigillariæ, Stigmariæ, Coniferæ—Monocotyledon of the coal-measures—Climate of the Coal period—Mountain Limestone—Marine Fauna of the Carboniferous period—Corals—Polyzoa, Crinoidea—Mollusca—Great number of fossil fish—Foraminifera.

Vegetation of the Coal period.—In the last chapter we have seen that the seams of coal, whether bituminous or anthracitic, are derived from the same species of plants, and Göppert has ascertained that the remains of every family of plants scattered through the shales and sandstones of the coal-measures are sometimes met with in the pure coal itself—a fact which adds greatly to the geological interest of this flora.

The Coal period was called by Adolphe Brongniart the age of Acrogens,[1] so great appears to have been the numerical preponderance of flowerless or cryptogamic plants of the families of ferns, club-mosses, and horse-tails. He reckoned the known species in 1849 at 500, and the number has been largely increased by recent search in spite of reductions owing to the discovery that different parts of even the same plants had been taken for distinct species. Notwithstanding these changes, Brongniart's generalisation concerning this flora still holds true, namely, that the state of the vegetable world was then extremely different from that now prevailing, not only because the cryptogamous plants constituted nearly the whole flora, but also because they were on the whole more highly developed than any belonging to the same class now existing, and united some forms of structure now only found separately and in distinct orders. The only phænogamous plants which constitute any feature in the coal are the coniferæ; monocotyledons appear to have been very rare, and angiospermous dicotyledons, with one or two doubtful exceptions, were wanting. For this we are in some measure prepared by what we have seen of the Secondary or Mesozoic floras if, consistently with the belief in the theory of evolution, we expect to find the prevalence of simpler and less specialised organisms in older rocks.

Ferns.—We are struck at the first glance with the similarity

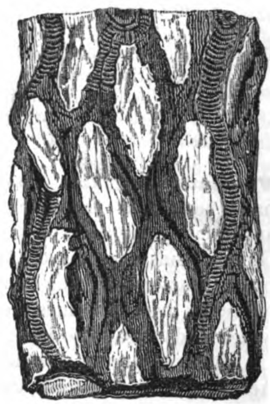
[1] For botanical nomenclature, see p. 287.

of the ferns to those now living. In the fossil genus *Pecopteris*, for example (fig. 452), it is not easy to decide whether the fossils might not be referred to the same genera as those established for

Fig. 452.

Pecopteris elliptica, Bunbury,[2] nat. size. Frostburg.

Fig. 453.



Caulopteris primæva, Lindley, ⅛.

living ferns; whereas, in regard to some of the other contemporary families of plants, with the exception of the fir-tribe, it is not easy to guess even the class to which they belong. The ferns of the Carboniferous period are generally without organs of fructification, but in the few instances in which these do occur in a fit state for microscopical investigations they agree with those of the living ferns.

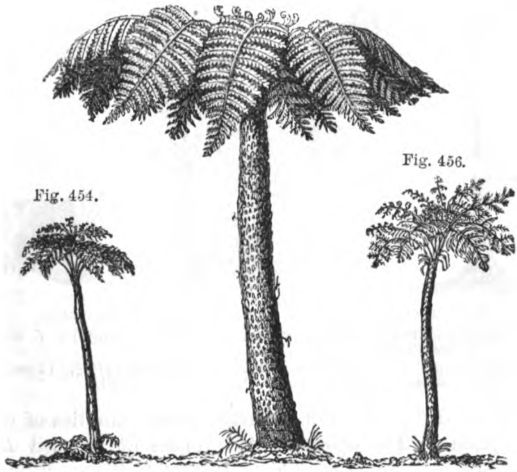
When collecting fossil specimens from the coal-measures of Frostburg in Maryland, I found in the iron-shales several species with well-preserved rounded spots or marks of the sori (see fig. 452). In the general absence of such characters they have been divided into genera, distinguished chiefly by the branching of the fronds and the way in which the veins of the leaves are disposed. The larger portion are supposed to have been of the size of ordinary European ferns, but some were decidedly arborescent, especially the group called *Caulopteris* (see fig. 453) by Lindley, and the *Psaronius* of the upper or newest coal-measures, before alluded to (p. 384). All the recent tree-ferns belong to one tribe (*Polypodiaceæ*), and to a small number only of genera in that tribe, in which the surface of the trunk is marked

[2] Sir C. Bunbury, Geol. Quart. Journ., vol. ii. 1845.

with scars, or cicatrices, left after the fall of the fronds. These scars resemble those of *Caulopteris*.

No less than 130 species of ferns are enumerated as having been obtained from the British coal-strata, and this number is more than doubled if we include the Continental and American

Fig. 455.



Living tree-ferns of different genera. (Ad. Brong.)
Fig. 454. Tree-fern from Isle of Bourbon.
Fig. 455. *Cyathea glauca*, Mauritius.
Fig. 456. Tree-fern from Brazil.

species. Even if we make some reduction on the ground of varieties which have been mistaken, in the absence of their fructification, for species, still the result is singular, because the whole of Europe affords at present no more than sixty-seven indigenous species.

Lycopodiaceæ.—*Lepidodendron.*—About forty species of fossil plants of the Coal have been referred to this genus, more than half of which are found in the British coal-measures. They consist of cylindrical stems or trunks, covered with leaf-scars. In their mode of branching they are always dichotomous (see fig. 458). They belong to the *Lycopodiaceæ*, bearing sporangia and spores similar to those of the living representatives of this family (fig. 461); and although most of the Carboniferous species grew to the size of large trees, Mr. Carruthers has found by careful measurement that the volume of the fossil spores did not exceed that of the recent club-moss—a fact of some geological importance, as it may help to explain the facility with

which these seeds may have been transported by the wind, causing the same wide distribution of the species of the fossil forests in Europe and America which we now observe in the

Fig. 457.

Fig. 458.

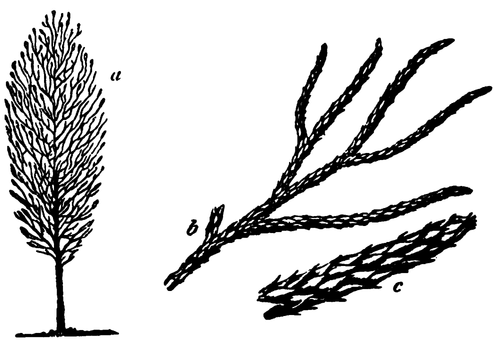
Fig. 459.

Lepidodendron Sternbergii. Coal-measures, near Newcastle.

Fig. 457. Branching trunk, 49 feet long, supposed to have belonged to *L. Sternbergii* (Foss. Flo. 203.)
458. Branching stem with bark and leaflets of *L. Sternbergii*, $\frac{2}{3}$. (Foss. Flo. 4.)
459. Portion of same nearer the root. Natural size. (Ibid.)

geographical distribution of so many living families of cryptogamous plants. The figs. 457–459 represent a fossil *Lepidodendron*, 49 feet long, found in Jarrow Colliery, near New-

Fig. 460.

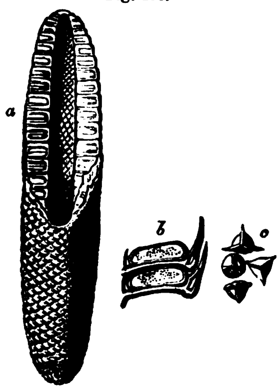


a. Lycopodium densum. Living species. New Zealand.
b. Branch; natural size. *c.* Part of same, magnified.

castle, lying in shale parallel to the planes of stratification. Fragments of others, found in the same shale, indicate, by the size of the rhomboidal scars which cover them, a still greater

magnitude. The living club-mosses, of which there are about 200 species, are most abundant in tropical climates. Thev usually creep on the ground, but some stand erect, as the *Lycopodium densum* from New Zealand (fig. 460), which attains a height of three feet.

Fig. 461.

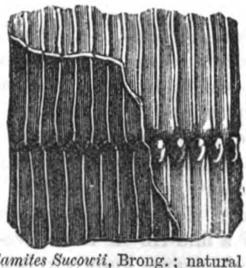


a. Lepidostrobus ornatus, Brong. (Strobilus or cone), Shropshire; ½ nat. size.
b. Portion of a section showing the large sporangia in their natural position.
c. Microspores occurring in these sporangia, highly magnified.[3]

In the Carboniferous strata of Coalbrook Dale, and in many other coal-fields, elongated cylindrical bodies, called fossil cones, and named *Lepidostrobus* by M. Adolphe Brongniart, are met with (see fig. 461). They often form the nucleus of concretionary balls of clay-ironstone, and are well preserved, exhibiting a conical axis, around which a great quantity of scales were compactly imbricated. The opinion of M. Brongniart, that the *Lepidostrobus* is the fruit of *Lepidodendron*, has been confirmed, for these *strobili* or fruits have been found terminating the tips of branches of well-characterised *Lepidodendra* in Coalbrook Dale and elsewhere.

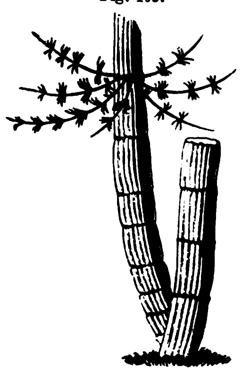
Equisetaceæ.—To this family belong two fossil genera of the

Fig. 462.



Calamites Sucowii, Brong.; natural size. Common in coal throughout Europe.

Fig. 463.

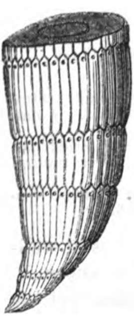


Stem of fig. 462, as restored by Dr. Dawson.

[3] Hooker, Mem. Geol. Survey, vol. ii. part 2, p. 440.

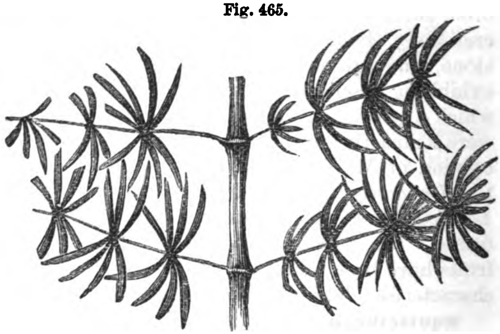
coal, *Equisetites* and *Calamites*. The Calamites were evidently closely related to the modern horse-tails (Equiseta), differing in their great size, the want of sheaths at the joints, and some details of fructification, and especially in the more complex and highly-organised structure of the woody zone resembling in appearance the structure of exogenous plants. They grew in dense brakes on sandy and muddy flats in the manner of modern Equisetaceæ, and their remains are frequent in the coal. Seven species of this plant occur in the great Nova Scotia section before described, where the stems of some of them five inches in diameter, and sometimes eight feet high, may be seen terminating downwards in a tapering root. Fig. 464 represents an inorganic cast of the internal cavity of a Calamite

Fig. 464.



Radical termination of a Calamite. Nova Scotia.

Fig. 465.



Asterophyllites foliosus. (Foss. Flo. 25.) Coal-measures, Newcastle.

stem, the ridges and furrows being impressions of the inner surface of the woody zone. The little tubercles seen near the articulations appear to be the scars of broken bundles of vessels.

Botanists are not yet agreed whether the *Asterophyllites* (see fig. 465) was the foliage of Calamites or not. Professor Williamson, from the microscopical examination of the internal structure of many well-preserved specimens, has come to the conclusion that the *Asterophyllites* did not belong even to the same natural order with the Calamites, but formed a distinct group, likewise Cryptogamous, but more nearly related to the Lycopodiums than to the Equisetums. Dr. Dawson inclines to the same view from the presence of a mid-rib in the leaves of Asterophyllites, which is wanting in the leaves known to belong to some Calamites. Professor Schimper and Mr. Carruthers, however, consider that Asterophyllites is the foliage of the Cala-

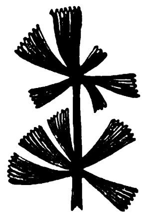
mite, and the latter even contends that he has found the leaves attached to a Calamite stem.

Figs. 466 and 467 represent leaves of *Annularia* and *Sphenophyllum*, common in the coal, and believed by Mr.

Fig. 466.

Annularia sphenophylloides, Zeuker.

Fig. 467.

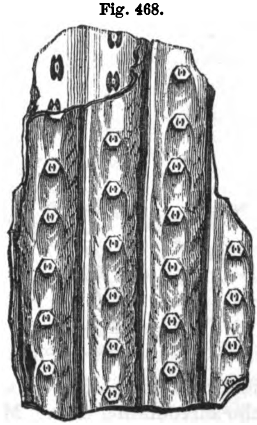


Sphenophyllum erosum, Lindley and Hutton.

Carruthers to be leaves of Calamites. There is still a difference of opinion as to whether these forms are or are not closely allied to *Asterophyllites*. Dr. Williamson, who has carefully studied the Calamites, thinks that they had a fistular pith, exogenous woody stem, and thick smooth bark, which last having always disappeared, leaves a fluted stem as represented in fig. 463.

Sigillaria.—A large portion of the trees of the Carboniferous period belonged to this genus, of which as many as twenty-eight species are enumerated as British. The structure, both internal and external, was very peculiar, and, with reference to existing types, very anomalous. They were formerly referred, by M. Ad. Brongniart, to ferns, which they resemble in the scalariform texture of their vessels, and in some degree in the form of the cicatrices left by the base of the leaf-stalks which have fallen off (see fig. 468). But some of them are ascertained to have had long linear leaves, quite unlike those of ferns. They grew to a great height, from 30 to 60, or even 70 feet, with regular cylindrical stems, and without branches, although some species were dichotomous towards the top. Their fluted trunks, from one to five feet in diameter, appear to have decayed more rapidly in

Fig. 468.



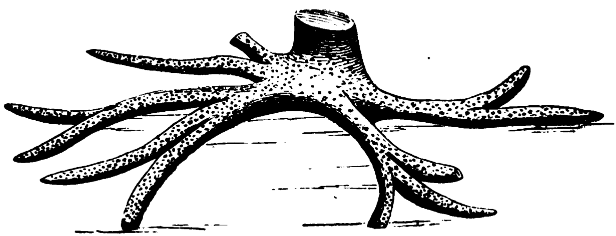
Sigillaria lævigata, Brong.

the interior than externally, so that they became hollow when standing; and when thrown prostrate, they were squeezed down and flattened. Hence, we find the bark of the two opposite sides (now converted into bright shining coal) constitute two horizontal layers, one upon the other, half an inch, or an inch, in their united thickness. These same trunks, when they are placed obliquely or vertically to the planes of stratification, retain their original rounded form, and are uncompressed, the cylinder of bark having been filled with sand, which now affords a cast of the interior.

Dr. Hooker inclined to the belief that the *Sigillariæ* may have been cryptogamous, though more highly developed than any flowerless plants now living. Dr. Dawson having found in some species what he regards as medullary rays, thinks with Brongniart that they have some relation to gymnogens, while Mr. Carruthers leans to the opinion that they belong to the Lycopodiaceæ.

Stigmaria.—This fossil, the importance of which has already been pointed out (p. 389), was originally conjectured to be an aquatic plant. It is now ascertained to be the root of *Sigillaria.* The connection of the roots with the stem, previously suspected, on botanical grounds, by Brongniart, was first proved, by actual contact, in the Lancashire coal-field, by Mr. Binney. The fact has lately been shown, even more distinctly, by Mr. Richard Brown, in his description of the *Stigmariæ* occurring in the underclays of the coal-seams of the island of Cape Breton, in Nova Scotia. In a specimen of one of these, represented in the annexed figure (fig. 469), the spread of the roots was sixteen

Fig. 469.



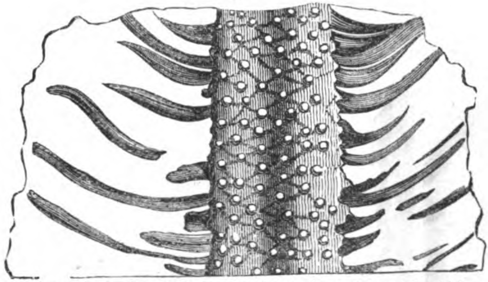
Stigmaria attached to a trunk of *Sigillaria.*

feet, and some of them sent out rootlets, in all directions, into the surrounding clay. Mr. Richard Brown also found Stigmarian roots in the coal-field of Cape Breton attached to trees believed by him to be Lepidodendra, and Mr. Carruthers has confirmed this opinion from specimens of Lepidodendron occurring

in British coal-fields. These facts are of great importance as helping to prove the affinity of *Sigillaria* and *Lepidodendron*, and thus confirming the opinion that the latter belong to the Lycopodiaceæ.

In the sea-cliffs of the South Joggins in Nova Scotia, I examined several erect *Sigillariæ*, in company with Dr. Dawson,

Fig. 470.



Stigmaria ficoides, Brong. ¼ natural size. (Foss. Flo. 32.)

and we found that from the lower extremities of the trunk they sent out *Stigmariæ* as roots. All the stools of the fossil trees dug out by us divided into four parts, and these again bifurcated, forming eight roots, which were also dichotomous when traceable far enough. The cylindrical rootlets formerly regarded as leaves are now shown by more perfect specimens to have been attached to the root by fitting into deep cylindrical pits. In the fossil there is rarely any trace of the form of these cavities, in consequence of the shrinkage of the surrounding tissues. Where the rootlets are removed nothing remains on the surface of the Stigmaria but rows of mammillated tubercles (see figs. 470, 471), which have formed the base of each rootlet. These protuberances may possibly indicate the place of a joint at the lower extremity of the rootlet. Rows of these tubercles are arranged spirally round each root, which have always a medullary axis and woody system much resembling that of *Sigillaria*, the structure of the vessels being, like it, scalariform. No instance seems yet to have been met with in Nova Scotia of Stigmarian roots attached to Lepidodendron.

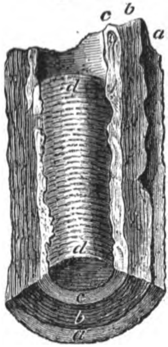
Fig. 471.

Surface of another individual of same species, showing form of tubercles. (Foss. Flo. 34.)

Coniferæ.—The coniferous trees of this period are referred to five genera; the woody structure of some of them showing

that they were allied to the Araucarian division of pines, more than to any of our common European firs. Some of their trunks exceeded forty-four feet in height. Many, if not all of them, seem to have differed from living *Coniferæ* in having large piths; for Professor Williamson has demonstrated the fossil of the coal-measures called *Sternbergia* to be the pith of these trees, or rather the cast of cavities formed by the shrinking or partial absorption of the original medullary axis (see figs. 472, 473).

Fig. 472.

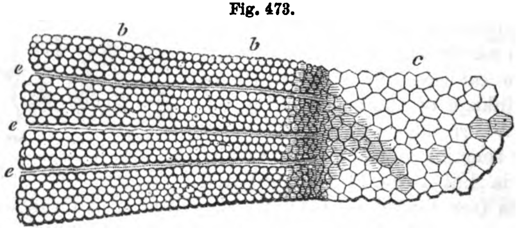


Fragment of coniferous wood, *Dadoxylon*, of Endlicher, fractured longitudinally; from Coalbrook Dale. W. C. Williamson.[4]

a. Bark.
b. Woody zone or fibre (pleurenchyma).
c. Medulla or pith.
d. Cast of hollow pith or 'Sternbergia.'

This peculiar type of pith is observed in living plants of very different families, such as the common Walnut and the White

Fig. 473.



Magnified portion of fig. 472; transverse section.
c. Pith. *b*, *b*. Woody fibre. *e*, *e*. Medullary rays.

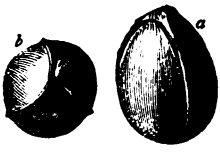
Jasmine, in which the pith becomes so reduced as simply to form a thin lining of the medullary cavity, across which transverse plates of pith extend horizontally, so as to divide the cylindrical hollow into discoid interspaces. When these interspaces have been filled up with inorganic matter, they constitute an axis to which, before their true nature was known, the provisional name of *Sternbergia* (*d*, *d*, fig. 472) was given. In the

[4] Manchester Phil. Mem., vol. ix. 1851.

above specimen the structure of the wood (*b*, figs. 472 and 443) is coniferous, and the fossil is referable to Endlicher's fossil genus *Dadoxylon*.

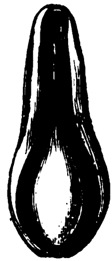
The fossil named *Trigonocarpum* (figs. 474 and 475), formerly

Fig. 474.



Trigonocarpum ovatum, Lindley and Hutton. Peel Quarry, Lancashire.

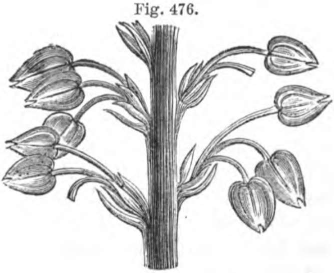
Fig. 475.



Trigonocarpum olivæforme, Lindley, with its fleshy envelope. Felling Colliery, Newcastle.

supposed to be the fruit of a palm, may now, according to Dr. Hooker, be referred, like the *Sternbergia*, to the *Coniferæ*. Its geological importance is great, for so abundant is it in the coal-measures that in certain localities the fruit of some species may be procured by the bushel; nor is there any part of the formation where they do not occur, except the underclays and limestone. The sandstone, ironstone, shales, and coal itself, all contain them. Mr. Binney has at length found in the clay-ironstone of Lancashire several specimens displaying structure, and from these, says Dr. Hooker, we learn that the *Trigonocarpum* belonged to that large section of existing coniferous plants which bear fleshy solitary fruits, and not cones. It resembled very closely the fruit of the Chinese genus, *Salisburia*, one of the Yew tribe, or Taxoid conifers.

Fig. 476.



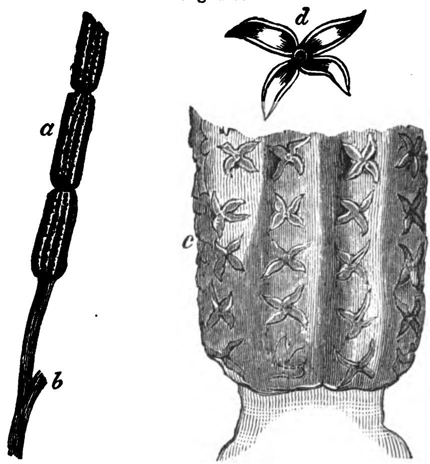
Cardiocarpon Lindleyi, Carr. (*Antholithes*, Lind.) Coal-measures, Falkirk.

The curious fossils called *Antholithes* by Lindley, which were formerly considered to be flower-spikes, are probably allied to the Coniferæ. No specimen has yet been found exhibiting structure, so that their true position is somewhat doubtful; but Mr. Peach in 1870 obtained specimens from carboniferous shales near Falkirk (see fig. 476), in which the fruit was attached to the stem,

and Mr. Carruthers has ascertained that these fruits are identical with others found in the coal-measures by Brongniart, and named by him *Cardiocarpon*. The processes supposed by Lindley to be petals prove to be pedicles of the fruit springing from each cluster of leaves on the axis. The fruit itself is flat and broadly ovate, with a cordate base, and a somewhat acute bifid apex.[5]

Monocotyledon in the coal-measures.—In the coal-measures of Granton, near Edinburgh, a remarkable fossil (fig. 477) was

Fig. 477.



Pothocites Grantonii, Pat. Coal-measures, Edinburgh.

a. Stem and spike; ½ nat. size. *b.* Remains of the spathe, magnified.
c. Portion of spike, magnified. *d.* One of the calyces, magnified.

found and described in 1840[6] by Dr. Robert Paterson. It was compressed between layers of bituminous shale, and consists of a stem bearing a cylindrical spike *a*, which in the portion preserved in the slate exhibits two subdivisions and part of a third. The spike is covered on the exposed surface with the four-cleft calyces of the flowers arranged in parallel rows. The stem shows, at *b*, a little below the spike, remains of a lateral appendage, which is supposed to indicate the beginning of the spathe. The fossil has been referred to the *Aroidiæ*, and there is every probability that it is a true member of this order. There can at least be no doubt as to the high grade of its organisation and that it belongs to the monocotyledons. Mr. Carruthers has

[5] Carruthers, Notes on Fossil Plants, Geol. Mag., vol. ix. 1872, p. 54.

[6] Trans. of Bot. Soc. Edinburgh, vol. i. 1844.

carefully examined the original specimen in the Botanical Museum, Edinburgh, and thinks it may have been an epiphyte.

Climate of the Coal Period.—As to the climate of the Coal, the Ferns and the Coniferæ are perhaps the two classes of plants which may be most relied upon as leading us to safe conclusions, as the genera are nearly allied to living types. All botanists admit that the abundance of ferns implies a moist atmosphere. But the coniferæ, says Hooker, are of more doubtful import, as they are found in hot and dry and in cold and dry climates, in hot and moist and in cold and moist regions. In New Zealand the coniferæ attain their maximum in numbers constituting $\frac{1}{62}$ part of all the flowering plants; whereas in a wide district around the Cape of Good Hope they do not form $\frac{1}{1600}$ of the phenogamic flora. Besides the conifers, many species of ferns flourish in New Zealand, some of them arborescent, together with many lycopodiums; so that a forest in that country may make a nearer approach to the carboniferous vegetation than any other now existing on the globe.

MARINE FAUNA OF THE CARBONIFEROUS PERIOD.

It has already been stated that the Carboniferous or Mountain Limestone underlies the coal-measures in the South of England and Wales, whereas in the North and in Scotland marine calcareous rocks partly of the age of the Mountain Limestone alternate with shales and sandstones, containing seams of coal. In its most calcareous form the Mountain Limestone is destitute of land-plants, and is loaded with marine remains—the greater part, indeed, of the rock being made up bodily of crinoids, corals, and polyzoa with interspersed mollusca.

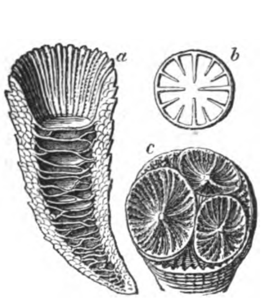
Corals.—The Corals deserve especial notice, as the cup-and-star corals, which have the most massive and stony skeletons, display peculiarities of structure by which they may be distinguished generally, as MM. Milne-Edwards and Haime first pointed out, from all species found in strata newer than the Permian. There is, in short, an ancient or *Palæozoic*, and a modern or *Neozoic* type, if by the latter term we designate (as proposed by Prof. E. Forbes) all strata from the triassic to the most modern, inclusive. The accompanying diagrams (figs. 478, 479) may illustrate these types.

It will be seen that the more ancient corals have what is called a quadripartite arrangement of the chief vertical plates or *lamellæ*—parts of the skeleton which support the organs of reproduction. The number of these lamellæ in the Palæozoic type is 4, 8, 16, &c.; while in the Neozoic type the number is

6, 12, 24, or some other multiple of six; and this holds good, whether they be simple forms, as in fig. 478, *a*, and 479, *a*, or aggregate clusters of corallites, as in 478, *c*. But further investigations have shown in this, as in all similar grand generalisations in natural history, that there are exceptions to the rule.

Fig. 478.

Palæozoic type of lamelliferous cup-shaped Coral. Order ZOANTHARIA RUGOSA, Milne-Edwards and Jules Haime.



a. Vertical section of *Campophyllum flexuosum* (*Cyathophyllum*, Goldfuss); ½ nat. size; from the Devonian of the Eifel. The *lamellæ* are seen around the inside of the cup; the walls consist of cellular tissue; and large transverse plates, called *tubulæ*, divide the interior into chambers.

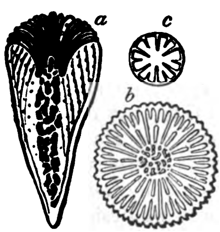
b. Arrangement of the *lamellæ* in *Polycœlia profunda*, Germar, sp.; nat. size; from the Magnesian Limestone, Durham. This diagram shows the quadripartite arrangement of the primary septa, characteristic of palæozoic corals, there being 4 principal and 8 intermediate lamellæ, the whole number in this type being always a multiple of four.

c. *Stauria astræiformis*, Milne-Edwards. Young group, nat. size. Upper Silurian, Gothland. The lamellæ or septal system in each cup are divided by four prominent ridges into four groups.

Thus in the Lower Greensand *Holocystis elegans* (Ed. and H.) and other forms have the Palæozoic type, and Dr. Duncan has

Fig. 479.

Neozoic type of lamelliferous cup-shaped Coral. Order ZOANTHARIA APOROSA, M. Edwards and J. Haime.



a. *Parasmilia centralis*, Mantell, sp. Vertical section; nat. size. Upper Chalk, Gravesend. In this type the *lamellæ* are massive, and extend to the axis or columella composed of loose cellular tissue, without any transverse plates like those in fig. 478, *a*.

b. *Cyathina Bowerbankii*, Ed. and H. Transverse section, enlarged. Gault, Folkestone. In this coral the primary septa are a multiple of six. The twelve principal plates reach the columella, and between each pair there are three secondaries, in all forty-eight. The short intermediate plates which proceed from the columella are not counted. They are called *pali*.

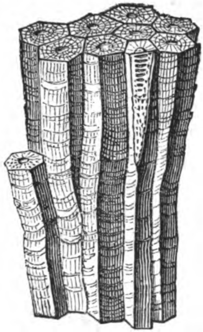
c. *Fungia patellaris*, Lamk. Recent; very young state. Diagram of its six primary and six secondary septa, magnified. The sextuple arrangement is always more manifest in the young than in the adult state.

shown to what extent the Neozoic forms penetrate downwards into the Carboniferous and Devonian rocks.

From a great number of rugose lamelliferous corals met with in the Mountain Limestone, two species (fig. 480, 481) have been selected, as having a very wide range, extending from the eastern borders of Russia to the British Isles, and being found

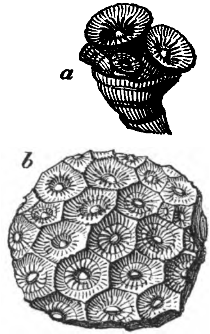
almost everywhere in each country. These fossils, together with numerous species of *Zaphrentis, Amplexus, Cyathophyllum,* and *Clisiophyllum,* form a group of rugose corals widely different

Fig. 480.



Lithostrotion basaltiforme, Phil. sp. ½. (*Lithostrotion striatum*, Fleming, *Astræa basaltiformis*, Conyb. and Phill.). England; Ireland; Russia; Iowa, and westward of the Mississippi, United States. (Dr. D. Owen.)

Fig. 481.

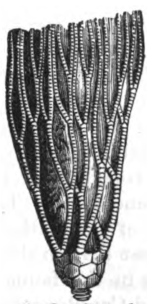


Lonsdaleia floriformis (Martin, sp.), M. Edwards, ½. (*Lithostrotion floriforme*, Fleming. *Strombodes*).
a. Young specimen, with buds or corallites on the disk, illustrating calicular gemmation. *b.* Part of a full-grown compound mass. Bristol, &c.; Russia.

from any that followed them. With them are associated certain tabulate corals, especially *Michelinia* and *Syringopora,* the latter of which often formed small reefs.[7]

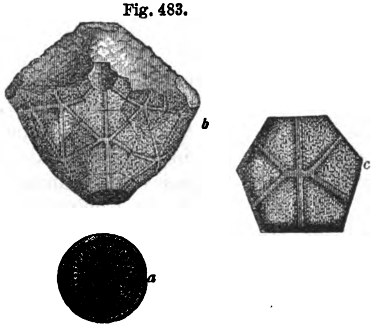
Polyzoa and Crinoidea.—Of the *Polyzoa,* the prevailing forms are *Fenestella, Hemitrypa,* and *Polypora,* and these often

Fig. 482.



Cyathocrinus planus, Miller.
Body and arms.
Mountain Limestone.

Fig. 483.



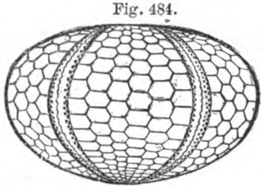
Cyathocrinus caryocrinoides, M'Coy.
a. Surface of one of the joints of the stem.
b. Pelvis or body; called also calyx or cup.
c. One of the pelvic plates.

[7] For figures of these corals, see Palæontographical Society's Monographs, 1852.

form considerable beds. Their net-like fronds are easily recognised. *Crinoidea* are also numerous in the Mountain Limestone (see figs. 482, 483).

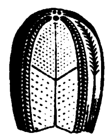
In the greater part of them, the cup or pelvis (fig. 483 *b*) is greatly developed in size in proportion to the arms, although this is not the case in fig. 482. The genera *Poteriocrinus*, *Cyathocrinus*, *Actinocrinus*, and *Platycrinus*, are all of them characteristic of this formation. Other Echinoderms are rare, a few Sea-Urchins only being known: these have a complex structure, with many more interambulacral plates than are seen in the modern genera of the same group. One genus, the *Palæchinus* (fig. 484), is the analogue of the modern *Echinus*, but has four, five, or six rows of plates in the interambulacral region or area, whereas the modern genera have only two. The

Fig. 484.



Palæchinus gigas, M'Coy, ⅓. Reduced one-third. Carboniferous Limestone. Ireland.

Fig. 485.



Pentremites elliptícus, Sow., ⅔. Carb. Limestone, Derbyshire, &c.

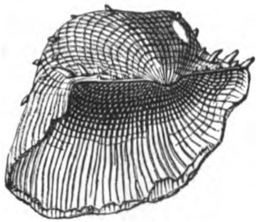
other, *Archæocidaris*, represents, in like manner, the *Cidaris* of the present seas. Two genera of Blastoidea, *Pentremites* and *Codonaster*, are peculiar to this formation in Europe and North America. *Pentremites* (fig. 485) is much the most abundant genus, and, like *Codonaster*, is distinguished from the true Crinoids and Cystoidea by the absence of arms.

Mollusca.—The British Carboniferous Mollusca enumerated by Mr. Etheridge [8] comprise 653 species referable to 86 genera, occurring chiefly in the Mountain Limestone. Of this large number only 40 species are common to the underlying Devonian rocks, 9 of them being Cephalopods, 7 Gasteropods, and the rest bivalves, chiefly Brachiopoda (Palliobranchiata). This latter group constitutes by far the larger part of the Carboniferous Mollusca, 157 species being known in Great Britain alone, and it will be found to increase in importance in the fauna of the Silurian rocks, especially in the Wenlock and Caradoc series. Perhaps the most characteristic shells of the formation are large species of *Productus*, such as *P. giganteus*, *P. semireticulatus*

[8] Quart. Geol. Journ., vol. xxiii. p. 674. 1867.

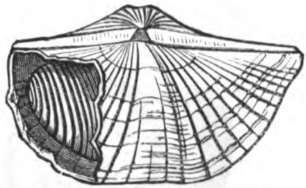
(fig. 486), and *P. scabriculus.* Large plaited spirifers, as *Spirifera striata*, *S. rotundata*, and *S. trigonalis* (fig. 487), also

Fig. 486.



Productus semireticulatus, Martin, sp., ½. (*P. antiquatus*, Sow.) Carboniferous Limestone. England; Russia; the Andes, &c.

Fig. 487.



Spirifera trigonalis, Martin, sp., nat. size. Carboniferous Limestone. Derbyshire, &c.

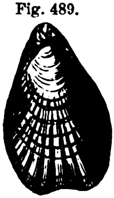
abound; and smooth species, such as *Spirifera glabra* (fig. 488), with its numerous varieties.

Among the brachiopoda, *Terebratula hastata* (fig. 489) deserves mention, not only for its wide range, but because it often retains the pattern of the original coloured stripes which ornamented the living shell. These coloured bands are also preserved in several lamellibranchiate bivalves, as in *Aviculopecten* (fig. 490), in which dark stripes alternate with a light ground. In some also of the spiral univalves, the pattern of the original painting is distinctly retained, as in *Pleurotomaria*

Fig. 488.

Spirifera glabra, Martin, sp ½. Carboniferous Limestone

Fig. 489.



Terebratula hastata, Sow., ⅔, with radiating bands of colour. Carboniferous Limestone. Derbyshire; Ireland; Russia, &c.

Fig. 490.

Aviculopecten sublobatus, Phill., nat. size. Carboniferous Limestone. Derbyshire; Yorkshire.

Fig. 491.

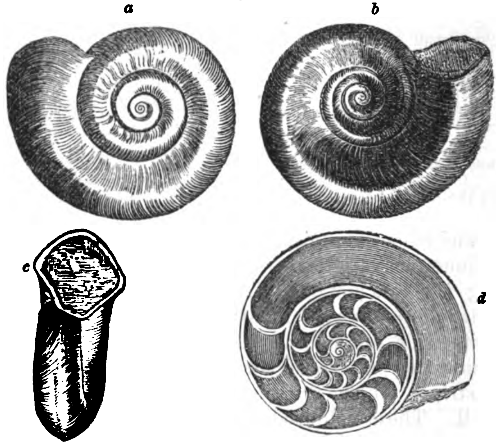
Pleurotomaria carinata, Sow., ⅔. (*P. flammigera*, Phill.) Carboniferous Limestone. Derbyshire, &c.

(fig. 491), which displays wavy blotches, resembling the colour-ng in many recent Trochidæ.

Some few of the carboniferous mollusca, such as *Avicula*,

Nucula (subgenus *Ctenodonta*), *Solemya*, and *Lithodomus*, belong no doubt to existing genera; but the majority, though often referred to as living types, such as *Isocardia*, *Turritella*, and *Buccinum*, belong really to forms which appear to have become extinct at the close of the Palæozoic epoch. *Euomphalus* is a characteristic univalve shell of this period. In the interior

Fig. 492.



Euomphalus pentangulatus, Sowerby, $\frac{2}{3}$. Mountain Limestone.
a. Upper side. *b.* Lower or umbilical side. *c.* View, showing mouth, which is less pentagonal in older individuals. *d.* View of polished section, showing internal chambers.

it is divided into chambers (fig. 492, *d*), the septa or partitions not being perforated as in foraminiferous shells, or in those having siphuncles, like the Nautilus. The animal appears to have retreated at different periods of its growth from the internal cavity previously formed, and to have closed all communication with it by a septum. The number of chambers is irregular, and they are generally wanting in the innermost whorl. The animal of the recent *Turritella communis* partitions off in like manner, as it advances in age, a part of its spire, forming a shelly septum.

Fig. 493.

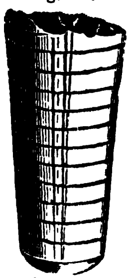
Bellerophon costatus, Sow. Nat. size. Mountain Limestone.

More than twenty species of the genus *Bellerophon* (see fig. 493), a shell like the living Argonaut without chambers, occur in the Mountain Limestone. The genus is not met with in strata of later date. It is most generally regarded as belonging

to the pelagic Nucleobranchiata and the family Atlantidæ, partly allied to the Glass-Shell, *Carinaria*; by some, however, it is thought to be a simple form of Cephalopod.

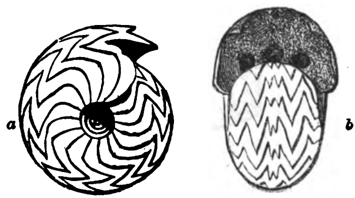
The carboniferous Cephalopoda do not depart so widely from the living type (the Nautilus) as do the more ancient Silurian representatives of the same order; yet they offer some remarkable forms. Among these is *Orthoceras*, a siphuncled and chambered shell, like a *Nautilus* uncoiled and straightened (fig. 494). Some species of this genus are several feet long.

Fig. 494.



Portion of *Orthoceras laterale*, Phillips, ½. Mountain Limestone.

Fig. 495.



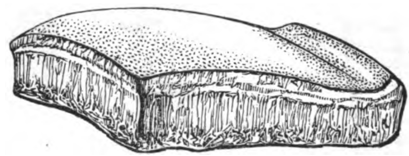
Goniatites crenistra, Phill., ⅔. Mountain Limestone. N. America; Britain; Germany, &c.
a. Lateral view.
b. Front view, showing the mouth.

The *Goniatite* is another genus, nearly allied to the *Ammonite*, from which it differs in having the lobes of the septa free from lateral denticulations, or crenatures; so that the outline of these is angular, continuous, and uninterrupted. The species represented in fig. 495 is found in most localities, and presents the zigzag character of the septal lobes in great perfection. The dorsal position of the siphuncle, however, clearly distinguishes the Goniatite from the Nautilus, and proves it to have belonged to the Ammonitidæ, from which, indeed, some authors do not believe it to be generically distinct.

Fossil Fish.—The distribution of these is singularly partial; so much so, that the eminent palæontologist, M. de Koninck, of Liége, once stated to me that, in making his extensive collection of the fossils of the Mountain Limestone of Belgium, he had found no more than four or five examples of the bones or teeth of fishes. Judging from Belgian data, he might have concluded that this class of vertebrata was of extreme rarity in the carboniferous seas; whereas the investigation of other countries has led to quite a different result. Thus, near Clifton, on the Avon, as well as at numerous places around the Bristol basin from the Mendip Hills to Tortworth, there is a celebrated 'bone-bed,' almost entirely made up of ichthyolites.

It occurs at the base of the Lower Limestone shales immediately resting upon the passage beds of the Old Red Sandstone. Similar bone-beds occur in the Carboniferous Limestone of Armagh, in Ireland, where they are made up chiefly of the teeth of Placoid fishes, nearly all of them rolled as if drifted from a distance. Some teeth are sharp and pointed, as in ordinary sharks, of which the genus *Cladodus* affords an illustration; but the majority, as in *Psammodus* and *Cochliodus*, are, like the teeth of the Cestraceon of Port Jackson (see above, fig. 263, p. 280), massive palatal teeth fitted for grinding (see figs. 496, 497).

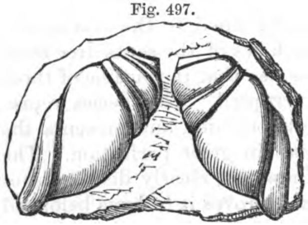
Fig. 496.



Psammodus porosus, Agass. Bone-bed, Mountain Limestone. Bristol; Armagh.

There are upwards of seventy other species of fossil fish known in the Mountain Limestone of the British Islands. The defensive fin-bones of these creatures are not unfrequent at Armagh and Bristol; those known as *Oracanthus*, *Ctenacanthus*, and *Onchus* are often of a very large size. Ganoid fish, such as *Holoptychius*, also occur; but these are far less numerous. The great *Megalichthys Hibberti* appears to range from the Upper Coal-measures to the lowest Carboniferous strata.

Fig. 497.



Cochliodus contortus, Agass. Bone bed, Mountain Limestone. Bristol; Armagh.

Foraminifera.—In the upper part of the Mountain Limestone group in the S.W. of England, near Bristol, limestones having a distinct oolitic structure alternate with shales. In these rocks the nucleus of almost every minute spherule is seen, under the microscope, to consist of a small rhizopod or foraminifer. This division of the lower animals, which is represented so fully at later epochs by the Nummulites and their numerous minute allies, appears in the Mountain Limestone to be restricted to a very few species, among which *Textularia*, *Nodosaria*, *Endothyra*, and *Fusulina* (fig. 498) have been recognised.

Fig. 498.

Fusulina cylindrica, D'Orb. Magnified 3 diam. Mountain Limestone.

The first two genera are common to this and all the after periods; the third has been found in the Upper Silurian, but is not known above the Carboniferous strata; the fourth (fig. 498) is characteristic of the Mountain Limestone in the United States, Arctic America, Russia, and Asia Minor, but is also known in the Permian.

CHAPTER XXV.

DEVONIAN OR RED SANDSTONE GROUP.

Classification of the Old Red Sandstone in Scotland and in Devonshire—Upper Old Red Sandstone in Scotland, with fish and plants—Middle Old Red Sandstone—Classification of the Ichthyolites of the Old Red, and their relation to living types—Lower Old Red Sandstone, with *Cephalapsis* and *Pterygotus*—Marine or Devonian type of Old Red Sandstone—Table of Devonian series—Upper Devonian rocks and fossils—Middle—Lower—Eifel Limestone of Germany—Devonian of Russia—Devonian Strata of the United States and Canada—Devonian Plants and Insects of Canada.

Classification of the two types of Old Red Sandstone.—We have seen that the Carboniferous strata are surmounted by the Permian and Trias, both originally included in England under the name 'New Red Sandstone,' from the prevailing red colour of the strata. Under the coal came other red sandstones and shales which were distinguished by the title of 'Old Red Sandstone.' Afterwards the name of 'Devonian' was given by Sir R. Murchison and Professor Sedgwick to marine fossiliferous strata which, in the South-west of England, occupy a similar position between the overlying coal and the underlying Silurian formations, the latter, however, not being exposed in North Devon.

It may be truly said that in the British Isles the rocks of this age present themselves in their mineral aspect, and even to some extent in their fossil contents, under two very different aspects; the one as distinct from the other as are often lacustrine or fluviatile from marine strata. It has indeed been suggested that by far the greater part of the deposits belonging to the Old Red Sandstone are of freshwater origin. The character of the land plants, and of the fishes, and the fact that the only shell yet discovered belongs to the genus *Anodonta*, must be allowed to lend no small countenance to this opinion. In this case the difficulty of classification when the strata of this type are compared in different regions, even where they are contiguous, may arise partly from their having been formed in distinct hydrographical basins, or in the neighbourhood of the land in shallow parts of the sea into which large bodies of fresh water entered, and where no marine mollusca or corals could flourish. Under such geographical conditions the limited extent of some kinds

of sediment as well as the absence of those marine forms by which we are able to identify or contrast marine formations, may be explained, while the great thickness of the rocks which might seem at first sight to require a corresponding depth of water can often be shown to have been due to the gradual sinking of the bottom of the estuary or sea in which the sediment was accumulated. Professor Ramsay, when speculating on this subject, has traced out the probable changes which marked the passage from the antecedent Silurian ocean to a continental condition at the time of the beginning of the Old Red Sandstone, when the sea was gradually converted first into a series of lagoons and finally into great freshwater lakes.

In Ireland and Scotland the upper division of the Old Red Sandstone lies unconformably upon the lower, and in South Wales the upper beds overlap the lower strata, 'indicating,' says Professor Ramsay, 'great disturbance and denudation,' but not presenting any insuperable difficulty as to the freshwater origin of the strata; for the explanation already given (p. 363) with regard to the Trias, of the manner in which overlapping strata might now be produced in the region of the Dead Sea, will apply equally to the Old Red formation. As regards the meagre fauna of the Old Red Sandstone, Professor Ramsay suggests that a parallel is to be found in the impoverished fauna of the Caspian Sea, which is now separated from the ocean and gradually growing salter by evaporation; but if by an increase of rainfall this inland sea were to become freshened, it would then exhibit a passage from marine to freshwater conditions very similar to that which marks the advent of the Old Red Sandstone.[1]

Another active cause of local variation in Scotland was the frequency of contemporaneous volcanic eruptions; some of the rocks derived from this source, as between the Grampians and the Tay, having formed islands in the sea, and having been converted into shingle and conglomerate, before the upper portions of the red shales and sandstones were superimposed.

A dearth of calcareous matter over wide areas is characteristic of the Old Red Sandstone. This is, no doubt, in great part due to the absence of shells and corals; but why should these be so generally wanting in all sedimentary rocks the colour of which is determined by the red oxide of iron? It cannot be said that any satisfactory conclusion has yet been arrived at on this subject. Some geologists are of opinion that the waters impregnated with this oxide were prejudicial to living beings; others that strata permeated with this oxide would not preserve

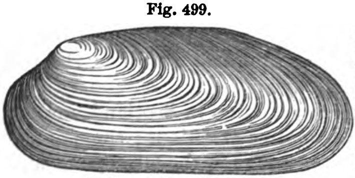
[1] Contemporary Review, July 1873, p. 200.

such fossil remains. We have already referred (p. 363) to the recent deposits of oxide of iron in certain Swedish lakes, a geological examination of which might, perhaps, throw light on this subject.

In regard to the two types, the Old Red Sandstone and the Devonian, I shall first treat of them separately, and then allude to the proofs of their having been to a great extent contemporaneous. That they constitute a series of rocks intermediate in date between the lowest Carboniferous and the uppermost Silurian is not disputed by the ablest geologists; and it can no longer be contended that the Upper, Middle, and Lower Old Red Sandstone preceded in date the three divisions to which by aid of the marine shells the Devonian rocks have been referred, while, on the other hand, we have not yet data for enabling us to affirm to what extent the subdivisions of the one series may be the equivalents in time of those of the other.

Upper Old Red Sandstone.—The highest beds of the series in Scotland, lying immediately below the coal in Fife, are composed of yellow sand stonewell seen at Dura Den near Cupar, in Fife, where, although the strata contain no mollusca, fish have been found abundantly, and have been referred to the genera *Holoptychius*, *Pamphractus*, *Glyptopomus*, and many others. In the county of Kilkenny, in Ireland, a similar yellow sandstone occurs containing fish of genera characteristic of the Scotch Old Red Sandstone, as for example *Coccosteus* (a form represented by many species in the Old Red Sandstone and by one only in the Carboniferous group) and *Glytolepis*, which is exclusively confined to the 'Old Red.' In the same Irish sandstone at Kiltorkan has been found an *Anodonta* or freshwater mussel, the only shell hitherto discovered in the Old Red Sandstone of the British Isles (see fig. 499). In the same beds are found the fern (fig. 501) and the *Lepidodendron* (fig. 500), and twelve other species of plants, some of which, Professor Heer remarks, agree specifically with species from the Lower Carboniferous beds. This induces him to lean to the opinion, long ago advocated by Sir Richard Griffith, that the yellow sandstone, in spite of its fish remains, should be classed as Lower Carboniferous—an opinion which I am not yet prepared to adopt. Between the Mountain Limestone and the yellow sandstone in the South-west of Ireland there intervenes a formation

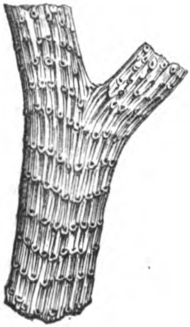
Fig. 499.



Anodonta Jukesii, Forbes, ½.
Upper Devonian, Kiltorkan, Ireland.

no less than 5,000 feet thick, called the 'Carboniferous slate;' and at the base of this, in some places, are local deposits, such

Fig. 500.



Bifurcating branch of *Lepidodendron Griffithsii*, Brong. Upper Devonian, Kilkenny.

Fig. 501.

Palæopteris Hibernica, Schimp. (*Cyclopteris Hibernica*, Ed. Forbes.) (*Adiantites*, Goep.) Upper Devonian, Kilkenny.

as the Coomhola Grits, which appear to be beds of passage between the Carboniferous and Old Red Sandstone groups.

It is a remarkable result of the recent examination of the fossil flora of Bear Island, lat. 74° 30′ N., that Professor Heer has described as occurring in that part of the Arctic region (nearly twenty-six degrees to the north of the Irish locality) a flora agreeing in several of its species with that of the yellow sandstones of Ireland. This Bear Island flora is believed by Professor Heer to comprise species of plants some of which ascend even to the higher stages of the European Carboniferous formation, or as high as the Mountain Limestone and Millstone Grit. Palæontologists have long maintained that the same species which have a wide range in space are also the most persistent in time, which may prepare us to find that some plants having a vast geographical range may also have endured from the period of the Upper Devonian to that of the Millstone Grit.

Outliers of the Upper 'Old Red' occur unconformably on older members of the group, and the formation represented at Whiteness, near Arbroath (*a*, fig. 55, p. 52), may probably be one of these outliers, though the want of organic remains renders this uncertain. It is not improbable that the beds given in this section as Nos. 1 and 2 may belong to the early part of the

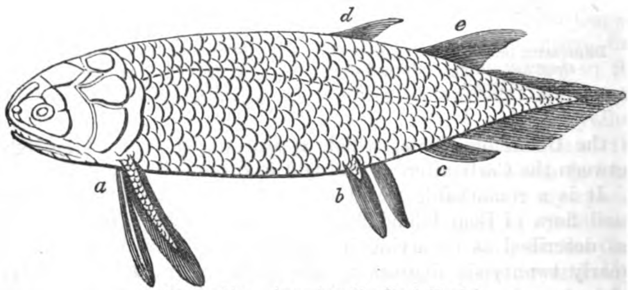
period of the Upper Old Red, as some scales of *Holoptychius nobilissimus* have been found scattered through the beds, No. 2, in Strathmore. Another nearly allied *Holoptychius* occurs in Dura Den. A figure of this genus is annexed (fig. 503), and also one of its scales (fig. 502), as these last are often the only parts met. with; being scattered in Forfarshire through red-coloured shales and sandstones, as are scales of a large species of the same genus in the yellow sandstone which forms the uppermost bed of the Old Red in Herefordshire and Shropshire.[2] The number of fish obtained from the British Upper Old Red Sandstone amounts to fifteen species referred to eleven genera.

Fig. 502.

Scale of *Holoptychius nobilissimus*, Ag. Clashbinnie, ½ nat. size.

Sir R. Murchison groups with this upper division of the Old

Fig. 503.



Holoptychius. As restored by Prof. Huxley.
a. The fringed pectoral fins. *c.* Anal fin.
b. The fringed ventral fins. *d, e.* Dorsal fins.

Red of Scotland certain light-red and yellow sandstones and grits which occur in the northernmost part of the mainland and extend also into the Orkney and Shetland Islands. They contain Calamites and other plants which agree generically with Carboniferous forms.

Middle Old Red Sandstone.—In the northern part of Scotland there occurs a great series of bituminous schists and flagstones, to the fossil fish of which attention was first called by the late Hugh Miller. They were afterwards described by Agassiz, and the rocks containing them were examined by Sir R. Murchison and Professor Sedgwick, in Caithness, Cromarty, Moray, Nairn, Gamrie in Banff, and the Orkneys and Shetlands, in which great numbers of fossil fish have been found. These

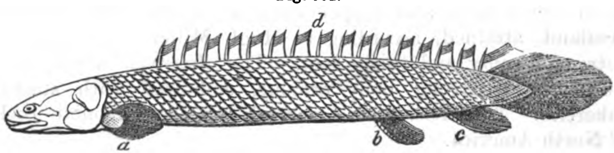
[2] Siluria, 4th ed. p. 265.

were at first supposed to be the oldest known vertebrate animals, as in Cromarty the beds in which they occur seem to form the base of the Old Red system resting almost immediately on the crystalline or metamorphic rocks. But in fact these fish-bearing beds, when they are traced from north to south, or to the central parts of Scotland, thin out, so that their relative age to the Lower Old Red Sandstone, presently to be mentioned, was not at first detected, the two formations not appearing in superposition in the same district. In Caithness, however, many hundred feet below the fish-zone of the middle division, remains of *Pteraspis* were found by Mr. Peach in 1861. This genus has never yet been found in either of the two higher divisions of the Old Red Sandstone, and confirms Sir R. Murchison's previous suspicion that the rocks in which it occurs belong to the Lower 'Old Red,' or agree in age with the Arbroath paving-stone.[3]

Fossil fish of the Middle Old Red Sandstone.—The Devonian fish were referred by Agassiz to two of his great orders, namely, the Placoids and Ganoids. Of the first of these, which in the recent period comprise the shark, the dog-fish, and the ray, no entire skeletons are preserved; but fin-spines, called Ichthyodorulites, and teeth occur. On such remains the genera *Onchus*, *Odontacanthus*, and *Ctenodus*, a supposed cestraciont, and some others, have been established.

By far the greater number of the Old Red Sandstone fishes belong to a sub-order of Ganoids instituted by Huxley in 1861, and for which he has proposed the name of *Crossopterygidæ*,[4] or the fringe-finned, in consideration of the peculiar manner in which the fin-rays of the paired fins are arranged so as to form a fringe round a central lobe, as in the *Polypterus* (see *a*, fig. 504), a genus of which there are several species now inhabiting

Fig. 504.



Polypterus. See Agassiz, 'Recherches sur les Poissons Fossiles.' Living in the Nile and other African rivers.

a. One of the fringed pectoral fins. *c.* Anal fin.
b. One of the ventral fins. *d.* Dorsal fin, or row of finlets.

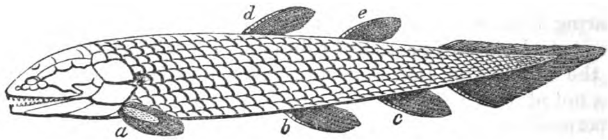
the Nile and other African rivers. The reader will at once recognise in *Osteolepis* (fig. 505), one of the common fishes of

[3] Siluria, 4th ed. p. 258.

[4] Abridged from κροσσωτος, crossotos, a fringe, and πτερυξ, pteryx, a fin.

the Old Red Sandstone, many points of analogy with *Polypterus.* They not only agree in the structure of the fin, as first pointed

Fig. 505.



Restoration of *Osteolepis.* Pander. Old Red Sandstone, or Devonian.

a. One of the fringed pectoral fins. *c.* Anal fins.
b. One of the ventral fins. *d, e.* Dorsal fins.

out by Huxley, but also in the position of the pectoral, ventral, and anal fins, and in having an elongated body and rhomboidal scales. On the other hand, the tail is more symmetrical in the recent fish, which has also an apparatus of dorsal finlets of a very abnormal charater, both as to number and structure. As to the dorsals of *Osteolepis,* they are regular in structure and position, having nothing remarkable about them, except that there are two, which is comparatively unusual in living fish.

Among the 'fringe-finned' Ganoids we find some with rhomboidal scales, such as *Osteolepis,* above figured; others with cycloidal scales, as *Holoptychius,* before-mentioned (see fig. 503, p. 438). In the genera *Dipterus* and *Diplopterus,* as Hugh Miller pointed out, and in several other of the fringe-finned genera, as in *Gyroptychius* and *Glyptolepis,* the two dorsals are placed far backwards, or directly over the ventral and anal fins. The *Asterolepis* (one of the Placodermata) was a ganoid fish of large dimensions. *A. Asmusii,* Eichwald, a species characteristic of the Old Red Sandstone (Devonian) of Russia, as well as of the Middle and Upper division of the same rocks in Scotland, attained, according to Hugh Miller,[5] the length of between twenty and thirty feet. The *Asterolepi* were partly clothed with strong bony armour, embossed with starlike tubercles. The *Asterolepis* occurs also in the Devonian rocks of North America.

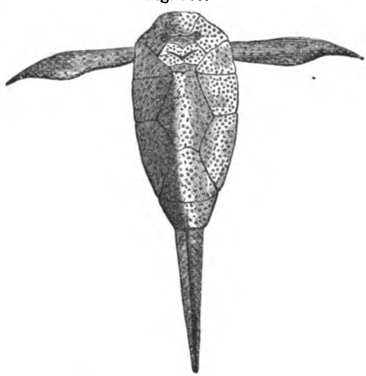
If we except the Placoids already alluded to, and a few other families of doubtful affinities, all the Old Red Sandstone fishes are Ganoids, an order so named by Agassiz from the shining outer surface of their scales; but Prof. Huxley has also called our attention to the fact, that, while a few of the primary and the great majority of the secondary Ganoids resemble the living bony pike, *Lepidosteus,* or the *Amia,* genera now found in North

[5] Footprints of Creation, p. 103.

American rivers, and one of them, *Lepidosteus*, extending as far south as Guatemala, the Crossopterygii, or fringe-finned Ichthyolites, of the Old Red are closely related to the African *Polypterus*, which is represented by five or six species now inhabiting the Nile and the rivers of Senegal. These North American and African Ganoids are quite exceptional in the living creation; they were until lately considered to be entirely confined to the northern hemisphere, but in 1870 another genus of the Crossopterygii, *Ceratodus Forsteri*, was found living in the rivers of Queensland, Australia;[6] out of about 9,000 living species of fish known to M. Günther, and of which more than 6,000 are now preserved in the British Museum, they probably constitute no more than nine.

If many circumstances favour the theory of the freshwater origin of the Old Red Sandstone, this view of its nature is not a little confirmed by our finding that it is in Lake Superior and the other inland Canadian freshwater seas, and in the Mississippi and African rivers, that we at present find those fish which have the nearest affinity to the fossil forms of this ancient formation.

Fig. 506.



Pterichthys, Agassiz; Upper side, showing mouth; as restored by H. Miller.

Among the anomalous forms of Old Red fishes not referable to Huxley's Crossopterygii is the *Pterichthys*, of which five species have been found in the middle division of the Old Red of Scotland. Some writers have compared their shelly covering to that of Crustaceans, with which, however, they have no real affinity. The wing-like appendages, whence the genus is named, were first supposed by Hugh Miller to be paddles, like those of the turtle; and there can now be no doubt that they do really correspond with the pectoral fins.

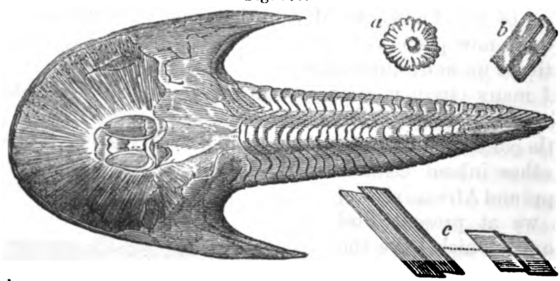
The number of species of fish already obtained from the middle division of the Old Red Sandstone in Great Britain is about 70, and the principal genera, besides *Osteolepis*, and *Pte-*

[6] Günther on Ceratodus, Phil. Trans. Royal Soc., part 2, 1871, p. 511.

richthys, already mentioned, are *Glyptolepis*, *Diplacanthus*, *Dendrodus*, *Coccosteus*, *Cheiracanthus*, and *Acanthoides*.

Lower Old Red Sandstone.—The third or lowest division south of the Grampians consists of grey paving stone and roofing-slate, with associated red and grey shales; these strata underlie a dense mass of conglomerate. In these grey beds several remarkable fish have been found of the genus named by Agassiz *Cephalaspis*, or 'buckler-headed,' from the extraordinary shield which covers the head (see fig. 507), and which has often

Fig. 507.

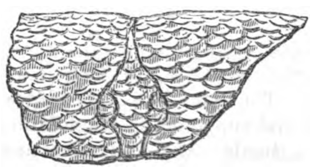


Cephalaspis Lyellii, Agass. Length 6¾ inches.
From a specimen in my collection found at Glamis, in Forfarshire.
(See other figures, Agassiz, vol. ii. tab. 1 *a* and 1 *b*.)

a. One of the peculiar scales with which the head is covered when perfect. These scales are generally removed, as in the specimen above figured.
b, *c*. Scales from different parts of the body and tail.

been mistaken for that of a trilobite, such as *Asaphus*. A species of *Pteraspis*, of the same family, has also been found by the Rev. Hugh Mitchell in beds of corresponding age in Perthshire; and Mr. Powrie enumerates no less than five genera of the family Acanthodidæ, the spines, scales, and other remains of which have been detected in the grey flaggy sandstones.[7]

Fig. 508.



Pterygotus anglicus, Agassiz.
Middle portion of the back of the head called the 'Seraphim.'

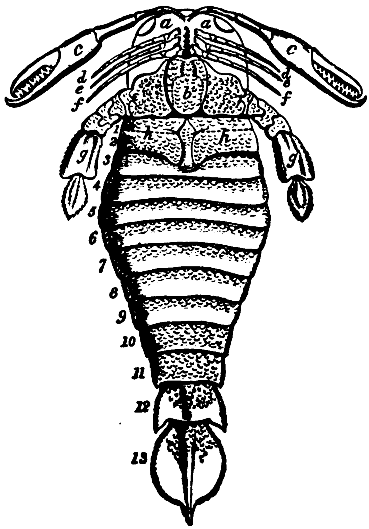
In the same formation at Carmylie, in Forfarshire, commonly known as the Arbroath paving-stone, fragments of a huge crustacean have been met with from time to time. They are called by the Scotch quarrymen the 'Seraphim,' from the wing-like form and feather-like ornament of the thoracic ap-

[7] Powrie, Geol. Quart. Journ., vol. xx. p. 417.

pendage, the part most usually met with. Agassiz, having previously referred some of these fragments to the class of fishes, was the first to recognise their crustacean character, and, although at the time unable correctly to determine the true relation of the several parts, he figured the portions on which he founded his opinion in the first plate of his 'Poissons Fossiles du Vieux Grès Rouge.'

A restoration in correct proportion to the size of the fragments of *P. Anglicus* (fig. 509), from the Lower Old Red Sandstone of Perthshire and Forfarshire, would give us a creature measuring from 5 to 6 feet in length, and more than 1 foot across.

Fig. 509.



Pterygotus anglicus. Ag., Forfarshire. Ventral aspect. Restored by H. Woodward, F.R.S.

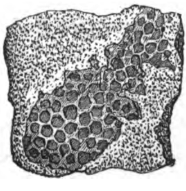
a. Carapace, showing the large sessile eyes at the anterior angles.
b. The *metastoma* or post-oral plate (serving the office of a lower lip).
c, *c*. Chelate appendages (*antennules*).
d. First pair of simple palpi (*antennæ*).
e. Second pair of simple palpi (*mandibles*).
f. Third pair of simple palpi (first *maxillæ*).
g. Pair of swimming feet with their broad basal joints, whose serrated edges serve the office of *maxillæ*.
h. Thoracic plate covering the first two thoracic segments, which are indicated by the figures 1, 2, and a dotted line.
1–6. Thoracic segments.
7-12. Abdominal segments.
13. Telson, or tail-plate.

The largest crustaceans living at the present day are the *Inachus Kæmpferi* of De Haan, from Japan (a brachyurous or short-tailed crab), chiefly remarkable for the extraordinary length of its limbs ; the fore-arm measuring 4 feet in length, and the others in proportion, so that it covers about 25 square feet of ground ; and the *Limulus Moluccanus*, the great King Crab of China and the Eastern seas, which, when adult, measures 1½ foot across its carapace, and is 3 feet in length.

Besides some species of *Pterygotus*, several of the allied genus *Eurypterus* occur in the Lower Old Red Sandstone, and with them the remains of grass-like plants so abundant in Forfar-

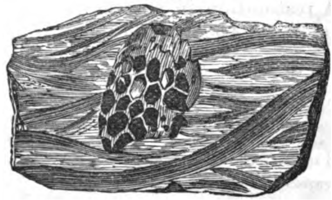
shire and Kincardineshire as to be useful to the geologist by enabling him to identify the inferior strata at distant points. Some botanists have suggested that these plants may be of the family *Fluviales*, and of freshwater genera. They are accompanied by fossils, called 'berries' by the quarrymen, which they compared to a compressed blackberry (see figs. 510, 511),

Fig. 510.



Parka decipiens, Fleming. In sandstone of lower beds of Old Red, Ley's Mill, Forfarshire.

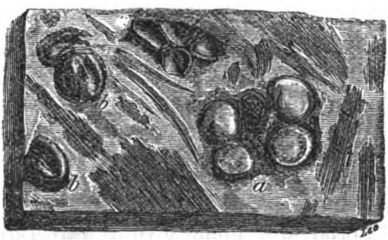
Fig. 511.



Parka decipiens, Fleming, nat. size. In shale of Lower Old Red, Park Hill, Fife.

and which were called 'Parka' by Dr. Fleming. They are now considered by Mr. Powrie to be the eggs of crustaceans; which is highly probable, for they have not only been found with *Pterygotus Anglicus* in Forfarshire and Perthshire, but also in

Fig. 512.



Old Red Sandstone Shale of Forfarshire. With impression of plants and ova of Crustaceans. Nat. size.

a. Two pair of ova? resembling those of large Salamanders or Tritons—on the same leaf.
b, *b*. Detached ova.

the Upper Silurian strata of England in which species of the same genus, Pterygotus, occur.

The grandest exhibitions, says Sir R. Murchison, of the Old Red Sandstone in England and Wales appear in the escarpments of the Black Mountains and in the Fans of Brecon and Carmarthen, the one 2,862, and the other 2,590 feet above the sea. The mass of red and brown sandstone in these mountains is estimated at not less than 10,000 feet, clearly intercalated between the Carboniferous and Silurian strata. No shells or corals have ever been found in the whole series, not even where the beds are calcareous, forming irregular courses of concretionary lumps called 'cornstones,' which may be described as

mottled red and green earthy limestones. The fishes of this lowest English Old Red are *Cephalaspis* and *Pteraspis*, specifically different from species of the same genera which occur in the uppermost Ludlow or Silurian tilestones. Crustaceans also of the genus *Eurypterus* are met with.

Marine or Devonian Type.—We may now speak of the marine type of the British strata intermediate between the Carboniferous and Silurian, in treating of which we shall find it much more easy to identify the Upper, Middle, and Lower divisions with strata of the same age in other countries. It was not until the year 1836 that Sir R. Murchison and Professor Sedgwick discovered that the culmiferous or anthracitic shales and sandstones of North Devon, several thousand feet thick, belonged to the coal; and that the beds below them, which are of still greater thickness, and which, like the carboniferous strata, had been confounded under the general name 'greywacke,' occupied a geological position corresponding to that of the Old Red Sandstone already described. In this reform they were aided by a suggestion of Mr. Lonsdale, who, after studying the Devonshire fossils, perceived that they belonged to a peculiar palæontological type of intermediate character between the Carboniferous and Silurian.

It is in the north of Devon that these formations may best be studied, where they have been divided into an Upper, Middle, and Lower Group, and where, although much contorted and folded, they have for the most part escaped being altered by intrusive trap-rocks and by granite, which in Dartmoor and the more southern parts of the same county have often reduced them to a crystalline or metamorphic state.

The following table exhibits the sequence of the strata or subdivisions as seen both on the sea-coast of the British Channel and in the interior of Devon. It will be seen that in all main points it agrees with the table drawn up in 1864 for the sixth edition of my 'Elements.' Mr. Etheridge[8] has since published an excellent account of the different subdivisions of the rocks and their fossils, and has also pointed out their relation to the corresponding marine strata of the Continent. The slight modifications introduced in my table since 1864 are the result of a tour made in 1870 in company with Mr. T. M'K. Hughes, when we had the advantage of Mr. Etheridge's memoir as our guide.

[8] Quart. Geol. Journ., vol. xxiii. 1867.

DEVONIAN SERIES IN NORTH DEVON.

Upper Devonian or Pilton Group.	(*a.*) Sandy slates and schists with fossils, 36 species out of 110 common to the Carboniferous group (Pilton, Barnstaple, &c.), resting on soft schists in which fossils are very abundant (Croyde, &c.), and which pass down into (*b.*) Yellow, brown, and red sandstone, with land plants (*Cyclopteris*, &c.) and marine shells. One zone, characterised by the abundance of Cucullæa (Baggy Point, Marwood, Sloly, &c.), resting on hard grey and reddish sandstone and micaceous flags; no fossils yet found (Dulverton, Pickwell, Down, &c.).
Middle Devonian or Ilfracombe Group.	(*a*) Grey glossy slates of considerable thickness, bearing quartz veins; no fossils yet recorded from these beds (Morthœ, Lee Bay, &c.). (*b.*) Slates and schists, with irregular courses of limestone containing shells and corals like those of the Torbay and Plymouth Limestone (Combe Martin, Ilfracombe, &c.).
Lower Devonian or Lynton Group.	(*a.*) Hard, greenish, red, and purple sandstone (Hangman Hill, &c.). (*b.*) Soft slates with subordinate sandstones—fossils numerous at various horizons—Brachiopoda, Corals, Encrinites, &c. (Valley of Rocks, Lynmouth, &c.).

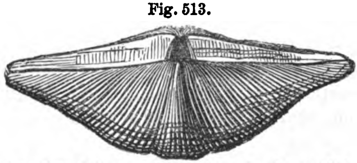
The place of the sandstones of the Foreland is not yet clearly made out, as they are cut off by a great fault and disturbance.

Upper Devonian Rocks.—The slates and sandstones of Barnstaple (*a* and *b* of the preceding section) contain the shell *Spirifera disjuncta*, Sow. (*S. Verneuilii*, Murch.), (see fig. 513), which has a very wide range in Europe, Asia Minor, and even China; also *Strophalosia caperata*, together with the large trilobite *Phacops latifrons*, Bronn. (see fig. 514), which is all but world-wide in its distribution. The fossils are numerous, and comprise about 150 species of mollusca, a fifth of

Fig. 514.

Phacops latifrons, Bronn, nat. size. Characteristic of the Devonian in Europe, Asia, and N. and S. America.

Fig. 513.

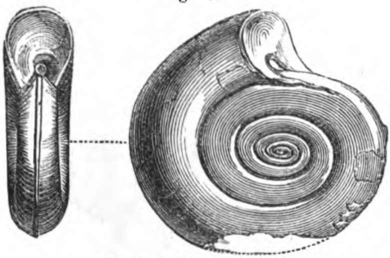


Spirifera disjuncta, Sow. Syn. *Sp. Verneuilii*, Murch., ½. Upper Devonian, Boulogne.

which pass up into the overlying Carboniferous rocks. To this

Upper Devonian belong a series of limestones and slates well developed at Petherwyn, in Cornwall, where they have yielded 75 species of fossils. The genus of Cephalopoda called *Clymenia* (fig. 515) is represented by no less than 11 species, and strata

Fig. 515.



Clymenia linearis, Münster.
Petherwyn, Cornwall; Elbersreuth, Bavaria.

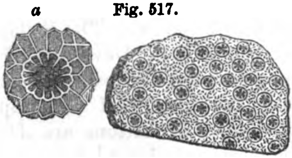
Fig. 516.

Cypridina serrato-striata, Sandberger, Weilburg, &c.; Cornwall; Nassau; Saxony; Belgium.

occupying the same position in Germany are called Clymenien-Kalk, or sometimes Cypridinen-Schiefer, on account of the number of minute bivalve shells of the crustacean called *Cypridina serrato-striata* (fig. 516), which is found in these beds, in the Rhenish provinces, the Harz, Saxony, and Silesia, as well as in Cornwall and Belgium.

Middle Devonian Rocks.—We come next to the most typical portion of the Devonian system, including the great limestones of Plymouth and Torbay, as well as the slates and impure limestones of Ilfracombe, all replete with shells, trilobites, and corals. Of the corals 51 species are enumerated by Mr. Etheridge, none of which pass into the Carboniferous formation. Among the genera we find *Favosites*, *Heliolites*, and *Cyathophyllum*. The two former genera are very frequent in Silurian rocks; some few even of the species are said to be common to the Devonian and Silurian groups, as for example, *Favosites cervicornis* (fig. 518), one of the commonest of all the Devonian corals. The *Cyathophyllum cæspitosum* (fig. 519) and *Heliolites porosa* (fig. 517) are species peculiar to this formation.

Fig. 517.

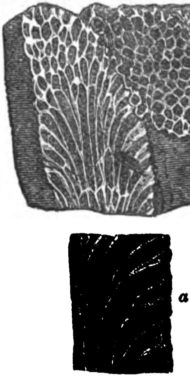


Heliolites porosa, Goldf., sp. (*Porites pyriformis*, Lonsd.), nat. size.
a. One of the corallites magnified.
Middle Devonian, Torquay. Plymouth, Eifel.

With the above are found no less than 11 genera of stone-lilies or crinoids, some of them, such as *Cupressocrinites*, distinct from any Carboniferous forms. The mollusca also are no less

characteristic; of 68 species of Brachiopoda, 10 only are common to the Carboniferous series. The *Stringocephalus*

Fig. 518.



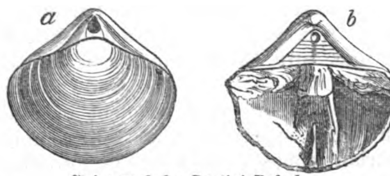
Favosites cervicornis, Blainv., nat. size. S. Devon, from a polished specimen.
a. Portion of the same magnified, to show the pores.

Fig. 519.

a. Cyathophyllum cæspitosum, Goldf., $\frac{1}{2}$; Plymouth and Ilfracombe.
b. A terminal star.
c. Vertical section, exhibiting transverse plates, and part of another branch.

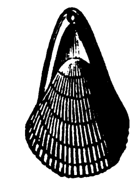
Burtini (fig. 520) and *Uncites Gryphus* (fig. 521) may be mentioned as exclusively Middle Devonian genera, and extremely

Fig. 520.



Stringocephalus Burtini, Def., $\frac{1}{2}$.
a. Valves united. *b.* Interior of ventral or large valve, showing thick partition and portion of a large process which projects from the dorsal valve across the shell.

Fig. 521.



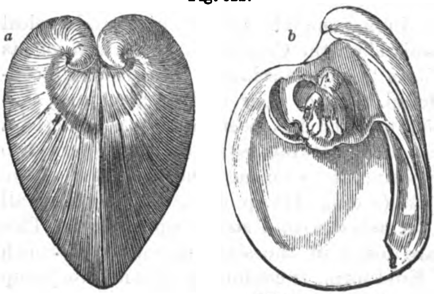
Uncites Gryphus, Def., $\frac{2}{3}$.
Middle Devonian.
S. Devon and the Continent.

characteristic of the same division in Belgium. The *Stringocephalus* is also so abundant in the Middle Devonian of the banks of the Rhine as to have suggested the name of Stringocephalus Limestone. The only two species of Brachiopoda common to the Silurian and Devonian formations are *Atrypa reticularis* (fig. 537, p. 459), which seems to have been a cosmopolite species, and *Strophomena rhomboidalis*.

Among the peculiar lamellibranchiate bivalves common to the Plymouth limestone of Devonshire and the Continent, we find

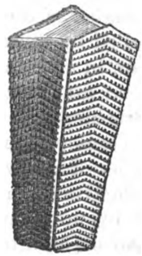
the *Megalodon* (fig. 522). There are also 12 genera of Gasteropods which have yielded 36 species, 4 of which pass to the Car-

Fig. 522.



Megalodon cucullatus, Sow. Eifel; also Bradley, S. Devon.
a. The valves united.
b. Interior of valve, showing the large cardinal tooth.

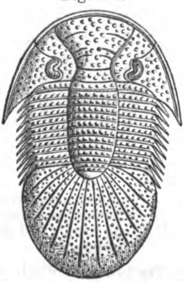
Fig. 523.



Conularia ornata, D'Arch. and De Vern, ⅔. (Geol. Trans., Sec. Ser., vol. vi. Pl. 29.) Refrath, near Cologne.

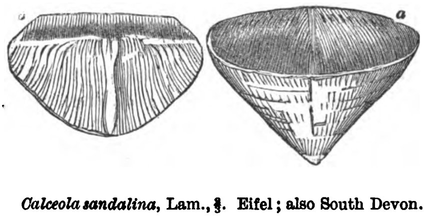
boniferous group, namely *Machrocheilus*, *Acroculia*, *Euomphalus*, and *Murchisonia*. Pteropods occur, such as *Conularia* (fig. 523), and the Cephalopods, *Cyrtoceras*, *Gyroceras*, *Orthoceras*, and others, nearly all of genera distinct from those prevailing in the Upper Devonian Limestone, or Clymenien-Kalk of the Germans already mentioned (p. 447). Although but few species of Trilobites occur, the characteristic *Bronteus flabellifer* (fig. 524) is far

Fig. 524.



Bronteus flabellifer, Goldf. Mid. Devon; S. Devon; and the Eifel.

Fig. 525.



Calceola sandalina, Lam., ⅔. Eifel; also South Devon.
a. Ventral valve.
b. Inner side of dorsal valve.

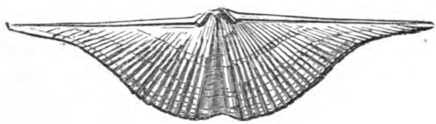
from rare, and all collectors are familiar with its fan-like tail. In this same group called, as before stated, the Stringocephalus or Eifel Limestone in Germany, several fish remains have been detected, and among others the remarkable genus *Coccosteus*,

covered with its tuberculated bony armour; and these ichthyolites serve, as Sir R. Murchison observes ('Siluria,' p. 362), to identify this middle marine Devonian with the Old Red Sandstone of Britain and Russia.

Beneath the Eifel Limestone (the great central and typical member of the 'Devonian' on the Continent) lie certain schists called by German writers 'Calceola-schiefer,' because they contain in abundance a fossil body of very curious structure, *Calceola sandalina* (fig. 525), which has been usually considered a Brachiopod, but which some naturalists have lately referred to a Goniophyllum, supposing it to be an abnormal form of the order *Zoantharia rugosa* (see fig. 478, p. 426), differing from all other corals in being furnished with a strong operculum. This is by no means a rare fossil in the slaty limestone of South Devon, and, like the Eifel form, is confined to the middle group of this country.

Lower Devonian Rocks.—A great series of sandstones and glossy slates, with Crinoids, Brachiopods, and some corals

Fig. 526.



Spirifera mucronata, Hall, nat. size. Devonian of Pennsylvania.

Fig. 527.

Homalonotus armatus, Burmeister, ½. Lower Devonian; Daun, in the Eifel; and S. Devon.

Obs. The two rows of spines down the body give an appearance of more distinct trilobation than really occurs in this or most other species of the genus.

and polyzoa, occurring on the coast at Lynmouth and the neighbourhood, and called the Lynton Group (see table, p. 446), form the lowest member of the Devonian in North Devon. Among the 18 species of all classes enumerated by Mr. Etheridge, two-thirds are common to the Middle Devonian; but only one, the ubiquitous *Atrypa reticularis*, can with certainty be identified with Silurian species. Among the characteristic forms are *Aveolites suborbicularis*, also common to this formation in the Rhine, and *Orthis arcuata*, very widely spread in the North Devon localities. But we may expect a large addition to the number of fossils whenever these strata shall have been carefully searched. The spirifer-sandstone of Sandberger, as exhibited in the rocks bordering the Rhine between Coblentz and Caub,

belong to this Lower division, and the same broad-winged Spirifers distinguish the Devonian strata of North America.

Among the Trilobites of this era several large species of *Homalonotus* (fig. 527) are conspicuous. The genus is still better known as a Silurian form, but the spinose species appear to belong exclusively to the 'Lower Devonian,' and are found in Britain, Europe, and the Cape of Good Hope.

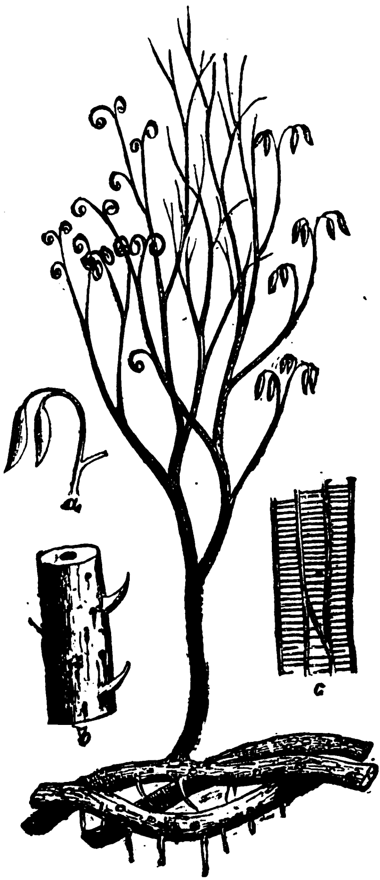
Devonian of Russia.—The Devonian strata of Russia extend, according to Sir R. Murchison, over a region more spacious than the British Isles; and it is remarkable that, where they consist of sandstone like the 'Old Red' of Scotland and Central England, they are tenanted by fossil fishes often of the same species and still oftener of the same genera as the British, whereas when they consist of limestone they contain shells similar to those of Devonshire, thus confirming, as Sir Roderick has pointed out, the contemporaneous origin which had been previously assigned to formations exhibiting two very distinct mineral types in different parts of Britain.[9] The calcareous and the arenaceous rocks of Russia above alluded to alternate in such a manner as to leave no doubt of their having been deposited in different parts of the same great period.

Devonian Strata in the United States and Canada.—Between the Carboniferous and Silurian strata there intervenes, in the United States and Canada, a great series of formations referable to the Devonian group, comprising some strata of marine origin abounding in shells and corals, and others of shallow water and littoral origin in which terrestrial plants abound. The fossils, both of the deep and shallow water strata, are very analogous to those of Europe, the species being in some cases the same. In Eastern Canada Sir W. Logan has pointed out that in the peninsula of Gaspé, south of the estuary of the St. Lawrence, a mass of sandstone, conglomerate, and shale referable to this period occurs, rich in vegetable remains, together with some fish-spines. Far down in the sandstones of Gaspé Dr. Dawson found in 1869 an entire specimen of the genus *Cephalaspis*, a form so characteristic, as we have already seen, of the Scotch Lower Old Red Sandstone. Some of the sandstones are ripple-marked; and towards the upper part of the whole series a thin seam of coal has been observed, measuring, together with some associated carbonaceous shale, about three inches in thickness. It rests on an underclay in which are the roots of Psilophyton (see fig. 528). At many other levels rootlets of this same plant have been shown by Principal

[9] Murchison's Siluria, p. 329.

Dawson to penetrate the clays, and to play the same part as do the rootlets of Stigmaria in the coal formation.

Fig. 528.



Psilophyton princeps, Dawson, Geol. Quart. Journ., vol. xv. 1863; and Canada Survey, 1863. Species characteristic of the whole Devonian series in North America.

a. Fruit; natural size. *b*. Stem; natural size. *c*. Scalariform tissue of the axis, highly magnified.

We had already learnt from the works of Gœppert, Unger, and Bronn that the European plants of the Devonian epoch resemble generically, with few exceptions, those already known as Carboniferous; and Dr. Dawson, in 1859, enumerated 32 genera and 69 species which he had then obtained from the State of New York and Canada. A perusal of his catalogue,[1] comprising *Coniferæ*, *Sigillariæ*, *Calamites*, *Asterophyllites*, *Lepidodendra*, and ferns of the genera *Cyclopteris*, *Neuropteris*, *Sphenopteris*, and others, together with fruits, such as *Cardiocarpum* and *Trigonocarpum*, might dispose geologists to believe that they were presented with a list of Carboniferous fossils, the difference of the species from those of the coal-measures, and even a slight admixture of genera unknown in Europe, being naturally ascribed to geographical distribution and the distance of the New from the Old World. But fortunately the coal formation is fully developed on the other side of the Atlantic, and is singularly like that of Europe, both lithologically and in the species of its

[1] Geol. Quart. Journ., vol. xv. p. 447, 1859; also vol. xviii. p. 296. 1862.

fossil plants. There is also the most unequivocal evidence of relative age afforded by superposition, for the Devonian strata in the United States are seen to crop out from beneath the carboniferous on the borders of Pennsylvania and New York, where both formations are of great thickness.

The number of American Devonian plants has now been raised by Dr. Dawson to 120, to which we may add about 80 from the European flora of the same age, so that already the vegetation of this period is beginning to be nearly half as rich as that of the coal-measures which have been studied for so much longer a time and over so much wider an area. The Psilophyton above alluded to is believed by Dr. Dawson to be a lycopodiaceous plant, branching dichotomously (see *P. princeps*, fig. 528), with stems springing from a rhizome, which last has circular areoles, much resembling those of Stigmaria, and like it sending forth cylindrical rootlets. The extreme points of some of the branchlets are rolled up so as to resemble the croziers or circinate vernation of ferns ; the leaves or bracts, *a*, supposed to belong to the same plant, are described by Dawson as having enclosed the fructification. The remains of *Psilophyton princeps* have been traced through all the members of the Devonian series in America, and Dr. Dawson has lately recognised it in specimens of Old Red Sandstone from the North of Scotland.

The monotonous character of the Carboniferous flora might be explained by imagining that we have only the vegetation handed down to us of one set of stations, consisting of wide swampy flats. But Dr. Dawson supposes that the geographical conditions under which the Devonian plants grew were more varied, and had more of an upland character. If so, the limitation of this more ancient flora represented by so many genera and species to the gymnospermous and cryptogamous orders, and the absence or extreme rarity of plants of higher grade, lead us naturally to speculate on the theory of progressive development, however difficult it may be to avail ourselves of this explanation.

Devonian Insects of Canada.—The earliest known insects were brought to light in 1865 in the Devonian strata of St. John's, New Brunswick, and are referred by Mr. Scudder to four species of *Neuroptera*. One of them is a gigantic Ephemera, and measured five inches in expanse of wing.

Like many other ancient animals, says Dr. Dawson, they show a remarkable union of characters now found in distinct orders of insects, or constitute what have been named 'synthetic types.' Of this kind is a stridulating or musical apparatus

like that of the cricket in an insect otherwise allied to the *Neuroptera*. This structure, as Dr. Dawson observes, if rightly interpreted by Mr. Scudder, introduces us to the sounds of the Devonian woods, bringing before our imagination the trill and hum of insect life that enlivened the solitudes of these strange old forests.

CHAPTER XXVI.

SILURIAN GROUP.

Classification of the Silurian rocks—Ludlow formation and fossils—Bone-bed of the Upper Ludlow—Lower Ludlow shales with *Pentamerus*—Oldest known remains of fossil fish—Table of the progressive discovery of vertebrata in older rocks—Wenlock formation, corals, cystideans, and trilobites—Llandovery group or beds of passage—Lower Silurian rocks—Caradoc and Bala Beds—Brachiopoda—Trilobites—Cystideæ—Graptolites—Llandeilo Flags—Arenig or Stiper-stones group—Foreign Silurian equivalents in Europe—Barrande's Silurian fauna—Silurian strata of the United States—Canadian equivalents—Amount of specific agreement of fossils with those of Europe.

Classification of the Silurian Rocks.—We come next in descending order to that division of Primary or Palæozoic rocks which immediately underlie the Devonian group of Old Red Sandstone. For these strata Sir Roderick Murchison first proposed the name of Silurian when he had studied and classified them in that part of Wales and some of the contiguous counties of England which once constituted the kingdom of the *Silures*, a tribe of ancient Britons. The following table will explain the two principal divisions, Upper and Lower, of the Silurian rocks, and the minor subdivisions usually adopted, comprehending all the strata originally embraced in the Silurian system by Sir Roderick Murchison. The formations below the Arenig or Stiper-stones group are treated of in the next chapter, when the Cambrian group is described.

UPPER SILURIAN ROCKS.

	Thickness in feet
1. LUDLOW FORMATION:	
a. Upper Ludlow beds	780
b. Lower Ludlow beds	1,050
2. WENLOCK FORMATION:	
a. Wenlock limestone and shale	above
b. Woolhope limestone and shale, and Denbighshire grits	4,000
3. LLANDOVERY FORMATION (Beds of passage between Upper and Lower Silurian):	
a. Upper Llandovery (May Hill beds)	800
b. Lower Llandovery	600—1,000

LOWER SILURIAN ROCKS.

	Thickness in feet
1. Bala and Caradoc Beds, including volcanic rocks .	12,000
2. Llandeilo Flags, including volcanic rocks . .	4,500
3. Arenig or Stiper-stones Group, including volcanic rocks	above 10,000

UPPER SILURIAN ROCKS.

1. Ludlow Formation.—This member of the Upper Silurian group, as will be seen by the above table, is of great thickness, and subdivided into two parts—the Upper Ludlow and the Lower Ludlow. Each of these may be distinguished near the town of Ludlow, and at other places in Shropshire and Herefordshire, by peculiar organic remains; but out of more than 500 species found in the Ludlow formation as a whole, not more than five species per cent. are common to the overlying Devonian. The student may refer to the excellent tables given in the last edition of Sir R. Murchison's 'Siluria' for a list of the organic remains of all classes distributed through the different subdivisions of the Upper and Lower Silurian.

a. **Upper Ludlow,** *Downton Sandstone.*—At the top of this subdivision there occur beds of fine-grained yellowish sandstone and hard reddish grits which were formerly referred by Sir R. Murchison to the Old Red Sandstone, under the name of 'Tilestones.' In mineral character this group forms a transition from the Silurian to the Old Red Sandstone; but it is now ascertained that the fossils agree in great part specifically, and in general character entirely, with those of the underlying Upper Ludlow rocks. Among these are *Orthoceras bullatum*, *Platyschisma helicites*, *Bellerophon trilobatus*, *Chonetes lata*, &c., with numerous defences of fishes.

These beds, therefore, now generally called the 'Downton Sandstone,' are classed as the newest member of the Upper Silurian. They are well seen at Downton Castle, near Ludlow, where they are quarried for building, and at Kington in Herefordshire. In the latter place, as well as at Ludlow, crustaceans of the genera Pterygotus (for genus see fig. 509, p. 443) and Eurypterus are met with.

Bone-bed of the Upper Ludlow.—At the base of the Downton sandstones there occurs a bone-bed which deserves especial notice as affording the most ancient example of fossil fish occurring in any considerable quantity. It usually consists of one or two thin layers of brown bony fragments near the junction of

the Old Red Sandstone and the Ludlow rocks, and was first observed by Sir R. Murchison near the town of Ludlow, where it is three or four inches thick. It has since been traced to a distance of 45 miles from that point into Gloucestershire and other counties, and is commonly not more than an inch thick, but varies to nearly a foot. Near Ludlow two bone-beds are observable, with 14 feet of intervening strata full of Upper Ludlow fossils.[1] Immediately above the upper fish-bed numerous small globular bodies have been found, which were formerly considered by Sir J. Hooker to be the sporangia of a cryptogamic land-plant, *Pachytheca sphærica*, probably lycopodiaceous.

Most of the fish remains have been referred by Agassiz to his placoid order, some of them to the genus Onchus, to which the spine (fig. 529) may be referred. The minute scales (fig. 530)

Fig. 529.

Onchus tenuistriatus, Agass., nat. size. Bone-bed. Upper Silurian; Ludlow.

Fig. 530.

Shagreen scales of a placoid fish, *Thecodus Parvidens*, Ag. Bone-bed. Upper Ludlow.

may also belong to a placoid fish. It has been suggested, however, that Onchus may be one of those Acanthodian fish, referred by Agassiz to his Ganoid order, which are so characteristic of the base of the Old Red Sandstone in Forfarshire, although the species of the Old Red are all different from these of the Silurian beds now under consideration. Associated with these fish defences or Ichthyodorulites, and closely resembling them, are numerous prongs or tail spines of large phyllopod crustaceans which have been and are still frequently mistaken for the dorsal spines of fish. The jaw and teeth of another predaceous genus, *Plectrodus mirabilis* (fig. 531), have also been detected, together with some specimens of *Pteraspis Ludensis*. As usual in bone-beds, the teeth and bones are, for the most part, fragmentary and rolled.

Fig. 531.

Plectrodus mirabilis, Agass. Nat. size. Bone-bed. Upper Ludlow.

Grey Sandstone and Mudstone, &c.—The next subdivision of the Upper Ludlow consists of grey calcareous sandstone, or very commonly a micaceous rock, decomposing into soft mud, and contains, besides the shells mentioned at p. 456, *Lingula cornea*, *Orthis orbicularis*, a round variety of *O. elegantula* (fig. 532), *Modiolopsis platyphylla*, *Grammysia cingulata*, all characteristic

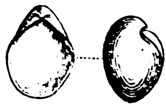
[1] Murchison's Siluria, p. 140.

of the Upper Ludlow. The lowest or mudstone beds contain *Rhynchonella navicula* (fig. 533), which is common to this bed

Fig. 532.

Orthis elegantula, Dalm., nat. size. Var. *Orbicularis*, Sow. Upper Ludlow.

Fig. 533.



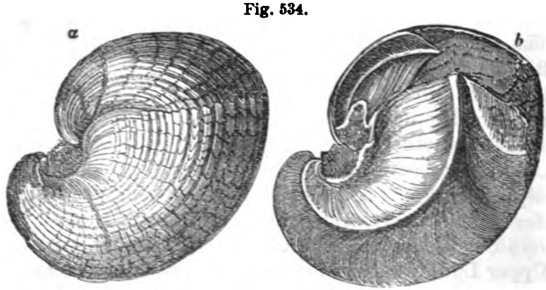
Rhynchonella navicula, Sow., nat. size. Ludlow Beds.

and the Lower Ludlow. As usual in Palæozoic strata older than the coal, the brachiopodous or palliobranchiate mollusca greatly outnumber the lamellibranchiate (see p. 469); but the latter are by no means unrepresented. Among other genera, for example, we observe *Avicula* and *Pterinea*, *Cardiola*, *Ctenodonta* (sub-genus of *Nucula*), *Orthonota*, *Modiolopsis*, and *Palæarca*.

Some of the Upper Ludlow sandstones are ripple-marked, thus affording evidence of gradual deposition; and the same may be said of the accompanying fine argillaceous shales, which are of great thickness, and have been provincially named 'mudstones.' In some of these shales stems of crinoidea are found in an erect position, having evidently become fossil on the spots where they grew at the bottom of the sea. The facility with which these rocks, when exposed to the weather, are resolved into mud, proves that, notwithstanding their antiquity, they are nearly in the state in which they were first thrown down.

Lower Ludlow Beds.—The chief mass of this formation consists of a dark grey argillaceous shale with calcareous con-

Fig. 534.



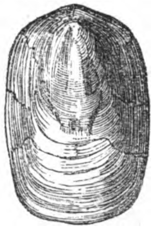
Pentamerus Knightii, Sow. Aymestry. ½ nat. size.

a View of both valves united. *b*. Longitudinal section through both valves, showing the central plates or septa.

cretions, having a maximum thickness of 1,000 feet. In some places, and especially at Aymestry in Herefordshire, a subcrys-

talline and argillaceous limestone, sometimes 50 feet thick, overlies the shale. Sir R. Murchison classes this Aymestry limestone as holding an intermediate position between the Upper and Lower Ludlow; but Mr. Lightbody remarks that at Mocktrie, near Leintwardine, the Lower Ludlow shales, with their characteristic fossils, occur both above and below a similar limestone. This limestone around Aymestry and Sedgeley is distinguished by the abundance of *Pentamerus Knightii*, Sow. (fig. 534), also found in the Wenlock limestone and shale. This genus of brachiopoda was first found in Silurian strata, and is exclusively a palæozoic form. The name was derived from *πεντε*, *pente*, five, and *μερος*, *meros*, a part, because both valves are divided by a central septum, making four chambers, and in one valve the septum itself contains a

Fig. 535.



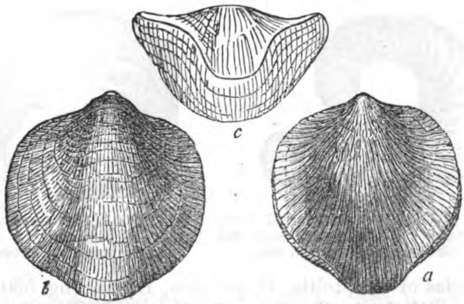
Lingula Lewisii, Sow., nat. size. Abberley Hills.

Fig. 536.

Rhynchonella (*Terebratula*) *Wilsoni*, Sow., nat. size. Aymestry.

small chamber, making five. The size of these septa is enormous compared with those of any other brachiopod shell; and they must nearly have divided the animal into two equal halves; but they are, nevertheless, of the same nature as the septa or

Fig. 537.



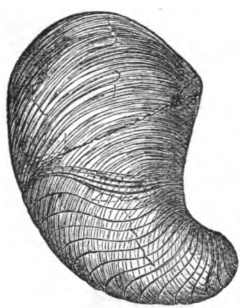
Atrypa reticularis, Linn., nat. size. (*Terebratula affinis*, Min. Con.). Aymestry.
a. Upper valve. *b*. Lower valve. *c*. Anterior margin of the valves.

plates which are found in the interior of *Spirifera*, *Uncites*, and many other shells of this order. Messrs. Murchison and De

Verneuil discovered this species dispersed in myriads through a white limestone of Upper Silurian age, on the banks of the Is, on the eastern flank of the Urals in Russia, and a similar species is frequent in Sweden.

Three other abundant shells in the Aymestry limestone are —1st, *Lingula Lewisii* (fig. 535); 2nd, *Rhynchonella Wilsoni*, Sow. (fig. 536), which is also common to the Lower Ludlow and Wenlock limestone; 3rd, *Atrypa reticularis*, Linn. (fig. 537), which has a very wide range, being found in every part of the Upper Silurian system, and even ranging up into the Middle Devonian series.

Fig. 538.



Phragmoceras ventricosum, J.Sow. (*Orthoceras ventricosum*, Stein). Aymestry. ½ nat. size.

The Aymestry Limestone contains many shells, especially brachiopoda, corals, trilobites, and other fossils, amounting on the whole to 74 species, all except three or four being common to the beds either above or below.

The Lower Ludlow Shale contains, among other fossils, many large cephalopoda not known in newer rocks, as the *Phragmoceras* of Broderip, and the *Lituites* of Breynius (see figs. 538, 539). The latter is partly straight and partly convoluted in a very flat spire. The *Orthoceras Ludense* (fig. 540), as well as the cephalopod last mentioned, occurs in this member of the series.

Fig. 539.

Lituites (*Trochoceras*) *giganteus*, J. Sow. Near Ludlow; also in the Aymestry and Wenlock Limestones. ½ nat. size.

Fig. 540.

Fragment of *Orthoceras Ludense*, J. Sow, ½. Leintwardine, Shropshire.

A species of Graptolite, *G. priodon*, Bronn. (fig. 550, p. 465), occurs plentifully in the Lower Ludlow. This fossil, referred, though somewhat doubtfully, to a form of hydrozoid or sertularian polyp, has not yet been met with in strata above the Silurian.

Star-fish, as Sir R. Murchison points out, are by no means rare in the Lower Ludlow rock. These fossils, of which 6 extinct genera are now known in the Ludlow series represented by 18 species, remind us of various living forms now found in our British seas, both of the families *Asteriadæ* and *Ophiuridæ*.

Dates of the discovery of different Classes of Fossil Vertebrata; showing the gradual progress made in tracing them to rocks of higher antiquity.

	Year — Formations	Geographical Localities
Mammalia	1798—Upper Eocene	Paris (Gypsum of Montmartre).[1]
	1818—Lower Oolite	Stonesfield.[2]
	1847—Upper Trias	Stuttgart.[3]
Aves . .	1782—Upper Eocene	Paris (Gypsum of Montmartre).[4]
	1839—Lower Eocene	Isle of Sheppey (London Clay).[5]
	1854— „ „	Woolwich Beds.[6]
	1855— „ „	Meudon (Plastic Clay).[7]
	1858—Chloritic series of Upper Greensand	Cambridge.[8]
	1863—Upper Oolite	Solenhofen.[9]
Reptilia (including Amphibia)	1810—Permian (Zechstein) . .	Thuringia.[10]
	1844—Carboniferous	Saarbrück, near Trèves.[11]
Pisces . .	1709—Middle Permian (Kupfer-schiefer).	Thuringia.[12]
	1793—Lower Carboniferous . .	Glasgow.[13]
	1828—Devonian	Caithness.[14]
	1840—Upper Ludlow . . .	Ludlow.[15]
	1859—Lower Ludlow . . .	Leintwardine.[16]

1 George Cuvier, Bulletin Soc. Philom. xx.
2 In 1818, Cuvier, visiting the Museum of Oxford, decided on the mammalian character of a jaw from Stonesfield. See also above, p. 333.
3 Plieninger, Prof. See above, p. 356.
4 Cuvier, Ossemens Foss., Art. 'Oiseaux.'
5 Owen, Prof., Geol. Trans., 2nd series, vol. vi. p. 203. 1839.
6 Upper part of the Woolwich beds. Prestwich, Quart. Geol. Journ., vol. x. p. 157
7 *Gastornis Parisiensis*. Owen, Quart. Geol. Journ., vol. xii. p. 204. 1856.
8 Coprolitic bed, in the Upper Greensand. See above, p. 283.
9 The *Archæopteryx macrura*, Owen. See above, p. 325.
10 The fossil monitor of Thuringia (*Protorosaurus Speneri*, V. Meyer) was figured by Spener, of Berlin, in 1810. (Miscel. Berlin.)
11 See above, p. 397.
12 Memorabilia Saxoniæ Subterr., Leipsic, 1709.
13 History of Rutherglen, by Rev. David Ure, 1793.
14 Sedgwick and Murchison, Geol. Trans., 2nd series, vol. iii. p. 141. 1828.
15 Sir R. Murchison. See above, p. 457.
16 See p. 462.

Obs.—The evidence derived from footprints, though often to be relied on, is omitted in the above table, as being less exact than that founded on bones and teeth.

Oldest known Fossil Fish.—Until 1859 there was no example of a fossil fish older than the bone-bed of the Upper

Ludlow; but in that year a specimen of Pteraspis was found at Church Hill, near Leintwardine in Shropshire, by Mr. J. E. Lee, of Caerleon, F.G.S., in shale below the Aymestry limestone, associated with fossil shells of the Lower Ludlow formation—shells which differ considerably from those characterising the Upper Ludlow already described. This discovery is of no small interest as bearing on the theory of progressive development, because, according to Professor Huxley, the genus Pteraspis is allied to the sturgeon, and therefore by no means of low grade in the piscine class.

It is a fact well worthy of notice that no remains of vertebrata have yet been met with in any strata older than the Lower Ludlow.

When we reflect on the hundreds of Mollusks, Echinoderms, Trilobites, Corals, and other fossils already obtained from the Silurian formations, Upper, Middle, and Lower, we may well ask, whether any set of fossiliferous rocks newer in the series were ever studied with equal diligence, and over so vast an area, without yielding a single ichthyolite. Yet we must hesitate before we accept, even on such evidence, so sweeping a conclusion, as that the globe, for ages after it was inhabited by all the great classes of invertebrata, remained wholly untenanted by vertebrate animals.

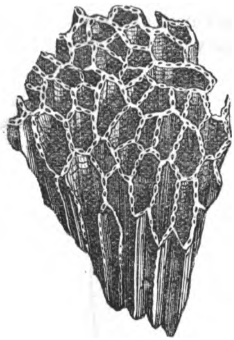
In the preceding Table (p. 461) a few dates are set before the reader of the discovery of different classes of animals in ancient rocks, to enable him to perceive at a glance how gradual has been our progress in tracing back the signs of vertebrata to formations of high antiquity. Such facts may be useful in warning us not to assume too hastily that the point which our retrospect may have reached at the present moment can be regarded as fixing the date of the first introduction of any one class of beings upon the earth.

2. **Wenlock Formation.**—We next come to the Wenlock formation, which has been divided (see Table, p. 455) into *a*, Wenlock limestone and Wenlock shale, and *b*, Woolhope limestone and Denbighshire grits.

a. Wenlock Limestone.—This limestone, otherwise well known to collectors by the name of the Dudley Limestone, forms a continuous ridge in Shropshire, ranging for about 20 miles from S.W. to N.E., about a mile distant from the nearly parallel escarpment of the Aymestry limestone. This ridgy prominence is due to the solidity of the rock, and to the softness of the shales above and below it. Near Wenlock it consists of thick masses of grey subcrystalline limestone, replete with corals, encrinites, and trilobites. It is essentially of a concretionary

nature; and the concretions, termed 'ball-stones' in Shropshire, are often enormous, even 80 feet in diameter. They are composed chiefly of carbonate of lime, the surrounding rock being more or less argillaceous.[2] Sometimes in the Malvern Hills this limestone, according to Professor Phillips, is oolitic.

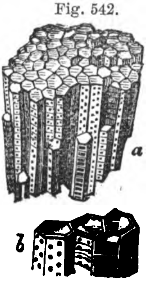
Fig. 541.



Halysites catenularius, Linn. sp., ½. Upper and Lower Silurian.

Among the corals in which this formation is so rich, 53 species being known, the 'chain-coral,' *Halysites catenularius* (fig. 541), may be pointed out as one very easily recognised, and widely spread in Europe, ranging through all parts of the Silurian group, from the Aymestry limestone to near the bottom of the Llandeilo rocks. Another coral, the *Favosites Gothlandica* (fig. 542), is also met with in profusion in large hemispherical masses, which break up into columnar and prismatic fragments, like that here figured (fig. 542, *b*). Another common form in the Wenlock limestone is the *Omphyma turbinatum* (fig. 543), which,

Fig. 542.



Favosites Gothlandica, Lam. Dudley.

a. Portion of a large mass; less than the natural size.
b. Magnified portion, to show the pores and the partitions in the tubes.

Fig. 543.

Omphyma turbinatum, Linn. sp., ½. (*Cyathophyllum*, Goldf.)

Wenlock Limestone, Shropshire.

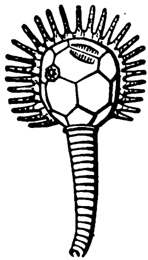
like many of its modern companions, reminds us of some cup-corals; but all the Silurian genera belong to the palæozoic type before mentioned (p. 425), exhibiting the quadripartite arrangement of the septal-lamellæ within the cup.

Among the numerous Crinoids, several peculiar species of *Cyathocrinus* (for genus, see figs. 482, 483, p. 427) contribute

[2] Murchison's Siluria, chap. vi.

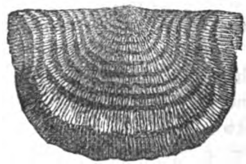
their dismembered calcareous stems, arms, and cups towards the composition of the Wenlock limestone. Of Cystideans there are a few very remarkable forms, most of them peculiar to the Upper Silurian formation ; as, for example, the *Pseudocrinites*, which was furnished with pinnated fixed arms,[3] as represented in the annexed figure (fig. 544).

Fig. 544.



Pseudocrinites bifasciatus, Pearce, $\frac{2}{3}$. Wenlock Limestone, Dudley.

Fig. 545.



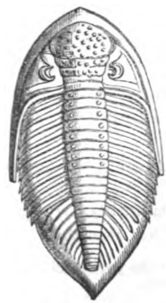
Strophomena (*Leptæna*) *depressa*, Sow., nat. size. Wenlock and Ludlow Rocks.

The Brachiopoda are, many of them, of the same species as those of the Aymestry limestone ; as, for example, *Atrypa reticularis* (fig. 537, p. 459) and *Strophomena depressa* (fig. 545) ; but the latter species ranges also from the Ludlow rocks, through the Wenlock shale, to the Caradoc sandstone.

Fig. 546.

Calymene Blumenbachii, Brong., $\frac{2}{3}$. Ludlow, Wenlock, and Bala Beds.

Fig. 547.



Phacops (*Asaphus*) *caudatus*, Brong., $\frac{2}{3}$. Wenlock and Ludlow Rocks.

Fig. 548.

Sphærexochus mirus, Beyrich, nat. size; coiled up ; Wenlock Limestone, Dudley ; also found in Ohio, N. America.

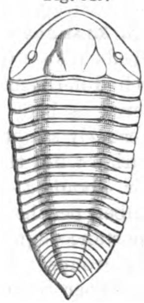
The Crustaceans are represented almost exclusively by Trilobites, which are very conspicuous, 22 being peculiar. The

[3] E. Forbes, Mem. Geol. Survey, vol. ii. p. 496.

Calymene Blumenbachii, called the 'Dudley Trilobite,' was known to collectors long before its true place in the animal kingdom was ascertained. It is often found coiled up like the common *Oniscus* or wood-louse, and this is so usual a circumstance among certain genera of trilobites as to lead us to conclude that they must have habitually resorted to this mode of protecting themselves when alarmed. The other common species is the *Phacops caudatus* (*Asaphus caudatus*), Brong. (see fig. 547), which is conspicuous for its large size and flattened form. *Sphærexochus mirus* (fig. 548) is almost gobular when rolled up, the forehead or glabellum of this species being extremely inflated. The *Homalonotus*, a form of Trilobite in which the tripartite division of the dorsal crust is almost lost (see fig. 549), is very characteristic of this division of the Silurian series.

Wenlock shale.—This, observes Sir R. Murchison, is infinitely the largest and most persistent member of the Wenlock formation, for the limestone often thins out and disappears. The shale, like the Lower Ludlow, often contains elliptical concretions of impure earthy limestone. In the Malvern district it is a mass of finely levigated argillaceous matter, attaining, according to Professor Phillips, a thickness of 640 feet; but it is sometimes more than 1,000 feet thick in Wales, and is worked for flagstones and slates. The prevailing fossils, besides corals and trilobites, and some crinoids, are several small species of *Orthis*, *Cardiola*, and numerous thin-shelled species of *Orthoceratites*.

Fig. 549.



Homalonotus delphinocephalus, Konig, ½. Wenlock Limestone, Dudley Castle.

Fig. 550.

Graptolithus priodon, Bronn, nat. size. Ludlow and Wenlock Shales.

About six species of *Graptolite*, a peculiar group of sertularian-like fossils before alluded to (p. 460) as being confined to Silurian rocks, occur in this shale. Of this genus, which is very characteristic of the Lower Silurian, I shall again speak in the sequel (p. 472).

b. Woolhope Beds.—Though not always recognised as a separate subdivision of the Wenlock, the Woolhope beds which underlie the Wenlock shale are of great importance. Usually they occur as massive or nodular limestones, underlaid by a fine shale or flagstone; and in other cases, as in the noted Denbighshire sandstones, as a coarse grit of very great thickness. This grit

forms mountain ranges through North and South Wales, and is generally marked by the great sterility of the soil where it occurs. It contains the usual Wenlock fossils, but with the addition of some common in the uppermost Ludlow rock, such as *Chonetes lata* and *Bellerophon trilobatus*. The chief fossils of the Woolhope limestone are *Illænus Barriensis*, *Homalonotus delphinocephalus* (fig. 549), *Strophomena imbrex*, and *Rhynchonella Wilsoni* (fig. 536). The latter attains in the Woolhope beds an unusual size for the species, the specimens being sometimes twice as large as those found in the Wenlock limestone.

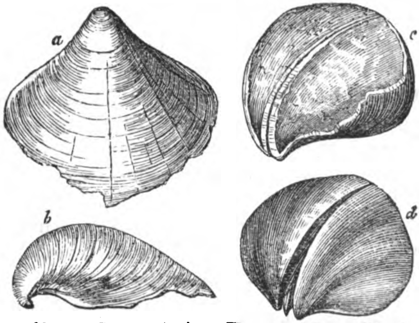
In some places below the Wenlock formation there are shales of a pale or purple colour which near Tarannon attain a thickness of about 1,000 feet; they can be traced through Radnor and Montgomery to North Wales, according to Messrs. Jukes and Aveline. By the latter geologist they have been identified with certain shales above the May Hill Sandstone near Llandovery, but owing to the extreme scarcity of fossils their exact position remains doubtful.

3. **Llandovery Group—Beds of Passage.**—We now come to beds respecting the classification of which there has been much difference of opinion, and which in fact must be considered as beds of passage between Upper and Lower Silurian. I formerly adopted the plan of those who class them as Middle Silurian; but they are scarcely entitled to this distinction, since, after about 1,400 Silurian species have been compared, the number peculiar to the group in question only gives them an importance equal to such minor subdivisions as the Ludlow or Bala groups. I therefore prefer to regard them as the base of the Upper Silurian, to which group they are linked by more than twice as many species as to the Lower Silurian. By this arrangement the line of demarcation between the two great divisions, though confessedly arbitrary, is less so than by any other. They are called Llandovery Rocks, from a town in South Wales in the neighbourhood of which they are well developed, and where, especially at a hill called Noeth Grüg, in spite of several faults their relations to one another can be clearly seen.

a. Upper Llandovery or May Hill Sandstone.—The May Hill group, which has also been named 'Upper Llandovery' by Sir R. Murchison, ranges from the west of the Longmynd to Builth, Llandovery, and Llandeilo, and to the sea in Marlow's Bay, where it is seen in the cliffs. It consists of brownish and yellow sandstones with calcareous nodules, having sometimes a conglomerate at the base derived from the waste of the Lower Silurian rocks. These May Hill beds were formerly supposed to

be part of the Caradoc formation, but their true position was determined by Professor Sedgwick[4] to be at the base of the Upper Silurian Proper. The more calcareous portions of the rock have been called the Pentamerus limestone, because *Pentamerus oblongus* (fig. 551) is very abundant in them. It is usually

Fig. 551.



Pentamerus oblongus, Sow., nat. size. Upper and Lower Llandovery beds.

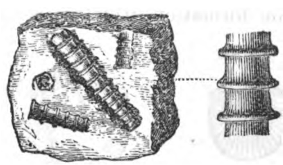
a, b. Views of the shell itself, from figures in Murchison's 'Sil. Syst.'
c. Cast with portion of shell remaining, and with the hollow of the central septum filled with spar.
d. Internal cast of a valve, the space once occupied by the septum being represented by a hollow in which is seen a cast of the chamber within the septum.

accompanied by *P.* (*Stricklandinia*) *lirata* (fig. 552); both forms have a wide geographical range, being also met with in the same part of the Silurian series in Russia and the United States.

Fig. 552.

Stricklandinia (*Pentamerus*) *lirata*, Sow., ½.

Fig. 553.



Tentaculites annulatus, Schlot. Interior casts in sandstone. Upper Llandovery, Eastnor Park, near Malvern.
Natural size and magnified.

About 228 species of fossils are known in the May Hill division, more than half of which are Wenlock species. They consist of Trilobites of the genera *Illænus* and *Calymene*; Brachiopods of the genera *Orthis*, *Atrypa*, *Leptæna*, *Pentamerus*, *Strophomena*, and others; Gasteropods of the genera *Turbo*,

4 1853. Quart. Geol. Journ., vol. ix. p 215.

Murchisonia (for genus, see fig. 572, p. 479), and *Bellerophon*; also Pteropods of the genus *Conularia*. The Brachiopoda, of which there are 66 species, are almost all Upper Silurian.

Among the fossils occurring in the May Hill shelly sandstone at Malvern, is *Tentaculites annulatus* (fig. 553), an annelid probably allied to *Serpula*.

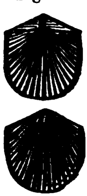
Lower Llandovery Rocks.—Below the May Hill Group are the Lower Llandovery Rocks, which consist chiefly of hard slaty rocks, and beds of conglomerate from 600 to 1,000 feet in thickness. The fossils, which are somewhat rare in the lower beds, consist of 128 known species, only 11 of which are peculiar, 83 being common to the May Hill group above, and 93 common to the rocks below. *Stricklandinia* (*Pentamerus*) *levis*, which is common to the Lower Llandovery, becomes rare in the Upper, while *Pentamerus oblongus* (fig. 551), which is the characteristic shell of the Upper Llandovery, occurs but seldom in the Lower.

LOWER SILURIAN ROCKS.

The Lower Silurian has been divided into—1st, the Bala Group; 2nd, the Llandeilo Flags; and, 3rdly, the Arenig or Lower Llandeilo formation.

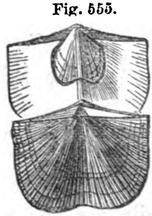
Bala and Caradoc Beds.—The Caradoc sandstone was originally so named by Sir R. I. Murchison from the mountain called Caer Caradoc in Shropshire; it consists of shelly sandstones of great thickness, and sometimes containing much calcareous matter. The rock is frequently laden with the beautiful trilobite called by Murchison *Trinucleus concentricus* (see fig. 558, p. 470), which ranges from the base to the summit of the formation, usually accompanied by *Strophomena grandis*

Fig. 554.



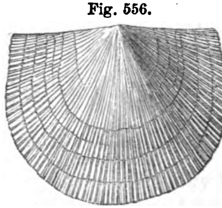
Orthis tricenaria, Conrad.
New York; Canada.
½ nat. size.

Fig. 555.



Orthis vespertilio, Sow.,
Shropshire; N. and S. Wales.
½ nat. size.

Fig. 556.



Orthis (*Strophomena*) *grandis*. Sow., ⅔ nat. size.
Caradoc Beds, Horderley, Shropshire; and Coniston, Lancashire.

(fig. 556) and *Orthis vespertilio* (fig. 555), with many other fossils.

Brachiopoda.—Nothing is more remarkable in these beds and

in the Silurian strata generally of all countries than the preponderance of Brachiopoda over other forms of mollusca. Their proportional numbers can by no means be explained by supposing them to have inhabited seas of great depth, for the contrast between the Palæozoic and the present state of things has not been essentially altered by the late discoveries made in our deep-sea dredgings. We find the living Brachiopoda so rare as to form about one forty-fourth of the whole bivalve fauna; whereas in the Lower Silurian rocks of which we are now about to treat, and where the Brachiopoda reach their maximum, they are represented by more than twice as many species as the Lamellibranchiate bivalves.

There may, indeed, be said to be a continued decrease of the proportional number of this lower tribe of mollusca as we proceed from older to newer rocks. In the British Devonian, for example, the Brachiopoda number 99, the Lamellibranchiata 58; while in the Carboniferous their proportions are more than reversed, the Lamellibranchiata numbering 334 species, and the Brachiopoda only 157. In the Secondary or Mesozoic formations the preponderance of the higher grade of bivalves becomes more and more marked, till in the Tertiary or Cainozoic strata it approaches that observed in the living creation.

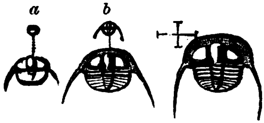
While on this subject it may be useful to the student to know that a Brachiopod differs from ordinary bivalves, mussels, cockles, &c., in being always equal-sided and never quite equivalved; the form of each valve being symmetrical, it may be divided into two equal parts by a line drawn from the apex to the centre or front of the margin.

Trilobites.—In the Bala and Caradoc beds the trilobites reach their maximum, being represented by 111 species referred to 23 genera.

Burmeister, in his work on the organisation of trilobites, supposes that they swam at the surface of the water in the open sea and near coasts, feeding on smaller marine animals, and had the power of rolling themselves into a ball as a defence against injury. He was also of opinion that they underwent various transformations analogous to those of living crustaceans. M. Barrande, author of an admirable work on the Silurian rocks of Bohemia, confirms the doctrine of their metamorphosis, having traced more than twenty species through different stages of growth from the young state just after its escape from the egg to the adult form. He has followed some of them from a point in which they show no eyes, no joints, or body rings, and no distinct tail, up to the complete form with the full number of segments. This change is brought about

before the animal has attained a tenth part of its full dimensions, and hence such minute and delicate specimens are rarely met with. Some of his figures of the metamorphoses of the common *Trinucleus* are copied in the annexed woodcuts (figs. 557, 558). In 1870 Mr. Billings suspected, from the appearance

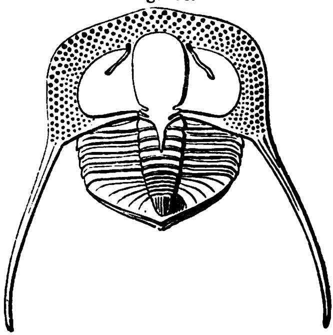
Fig. 557.



Young individuals of *Trinucleus concentricus* (*T. ornatus*, Barr.)

a. Youngest state. Natural size and magnified; the body rings not at all developed.
b. A little older. One thorax joint.
c. Still more advanced. Three thorax joints. The fourth, fifth, and sixth segments are successively produced, probably each time the animal moulted its crust.

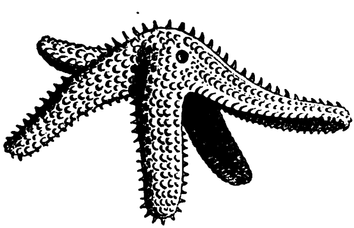
Fig. 558.



Trinucleus concentricus, Eaton.
Syn. *T. Caractaci*, Murch., nat. size.
Ireland; Wales; Shropshire; N. America; Bohemia.

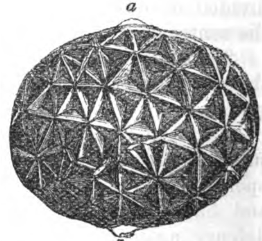
of a specimen found in Canada, that the trilobite was provided with eight legs; but Professor Dana, having thoroughly ex-

Fig. 559.



Palæaster asperimus, Salt.
Caradoc, Welshpool.

Fig. 560.



Echinosphærites balticus, Eichwald, nat. size. (Of the family *Cystideæ*.)

a. Mouth.
b. Point of attachment of stem.
Lower Silurian S. and N. Wales.

amined the fossil, came to the conclusion that the organs were not legs, but the semi-calcified arches in the membrane of the ventral surface to which the foliaceous appendages or legs were attached.[5]

[5] Nature, vol. iv. 1871, p. 152.

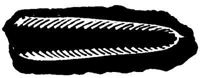
It has been ascertained that a great thickness of slaty and crystalline rocks of South Wales, as well as those of Snowdon and Bala, in North Wales, which were first supposed to be of older date than the Silurian sandstones and mudstones of Shropshire, are in fact identical in age, and contain the same organic remains. At Bala, in Merionethshire, a limestone rich in fossils occurs, in which two genera of star-fish, *Protaster* and *Palæaster*, are found, the latter (fig. 559) being almost as uncompressed as if found just washed up on the sea-beach. Besides the star-fish there occur many of those peculiar bodies called *Cystideæ*. They are the *Sphæronites* of old authors, and were considered by Professor E. Forbes as intermediate between the crinoids and echinoderms. The *Echinosphærites* here represented (fig. 560) is characteristic of the Caradoc beds in Wales, and of their equivalents in Sweden and Russia.

With it have been found several other genera of the same family, such as *Sphæronites*, *Hemicosmites*, &c. Among the mollusca are Pteropods of the genus *Conularia* of large size (for genus, see fig. 523, p. 449). About 11 species of Graptolites are reckoned as belonging to this formation ; they are chiefly found in peculiar localities where black mud abounds. The formation, when traced into South Wales and Ireland, assumes a greatly altered mineral aspect, but still retains its characteristic fossils. The known fauna of the Bala group comprises 565 species, 352 of which are peculiar, and 93, as before stated, are common to the overlying Llandovery rocks. It is worthy of remark that, when it occurs under the form of trappean tuff (volcanic ashes of De la Beche), as in the crest of Snowdon, the peculiar species which distinguish it from the Llandeilo beds are still observable. The formation generally appears to be of shallow-water origin, and in that respect is contrasted with the group next to be described. Professor Ramsay estimates the thickness of the Bala beds, including the contemporaneous volcanic rocks, stratified and unstratified, as being from 10,000 to 12,000 feet.

Llandeilo Flags.—The Lower Silurian strata were originally divided by Sir R. Murchison into the upper group already described under the name of Caradoc Sandstone, and a lower one, called, from a town in Caermarthenshire, the *Llandeilo* flags. The last-mentioned strata consist of dark-coloured argillaceous and micaceous flags, frequently calcareous, with a great thickness of shales, generally black, below them. The same beds are also seen at Abereiddy Bay in Pembrokeshire and at Builth in Radnorshire, where they are interstratified with volcanic matter.

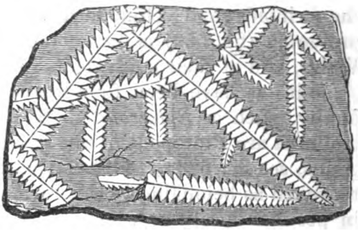
A still lower part of the Llandeilo rocks consists of a black carbonaceous slate of great thickness, frequently containing sulphuret of iron, and sometimes, as in Dumfriesshire, beds of anthracite. It has been conjectured that this carbonaceous matter may be due in great measure to large quantities of embedded animal remains, for the number of Graptolites included in these slates was certainly very great. In Great Britain 15 genera and about 90 species of Graptolites occur in the Llandeilo flags and underlying Arenig beds. The double Graptolites, or those with two rows of cells, such as *Diplograpsus* (fig. 562), are conspicuous.

Fig. 561.



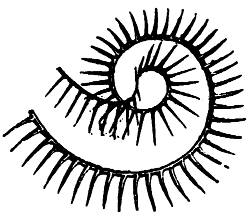
Didymograpsus (*Graptolites*) *Murchisonii*, Beck, ½.
Llandeilo flags, Wales.

Fig. 562.



Diplograpsus pristis, Hisinger, nat. size.
Llandeilo beds, Waterford.

Fig. 563.



Rastrites peregrinus, Barrande, nat. size.
Scotland; Bohemia; Saxony; Llandeilo flags.

Fig. 564.

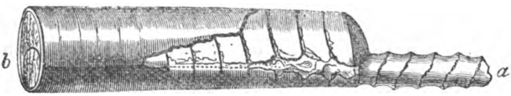
Diplograpsus folium, Hisinger.
Dumfriesshire; Sweden.
Llandeilo flags.

The Brachiopoda of the Llandeilo flags, which number 47 species, are in the main the same as those of the Caradoc Sandstone, but the other mollusca are mostly of different species.

In Europe generally, as, for example, in Sweden and Russia, no shells are so characteristic of this formation as Orthoceratites, usually of great size, and with a wide siphuncle placed on one side instead of being central (see fig. 565). Among other Cephalopods in the Llandeilo flags is Cyrtoceras (see p. 482), a slightly curved Orthoceras having the siphuncle on the dorsal edge; in the same beds also are found Bellerophon (see fig. 493, p. 430) and some Pteropod shells (*Conularia*, *Theca*, &c.); also in spots where sand abounded lamellibranchiate bivalves of large

size. The Crustaceans were plentifully represented by the Trilobites, which appear to have swarmed in the Silurian seas,

Fig. 565.

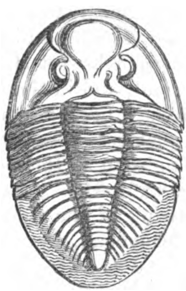


Orthoceras duplex, Wahlenberg. Russia and Sweden.
(From Murchison's 'Siluria.')

a. Lateral siphuncle laid bare by the removal of a portion of the chambered shell
b. Continuation of the same seen in a transverse section of the shell.

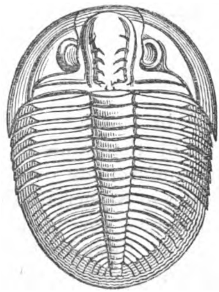
just as crabs and shrimps do in our own; no less than 263 species have been found in the British Silurian fauna. The genera *Asaphus* (fig. 566), *Ogygia* (fig. 567) and *Trinucleus*

Fig. 566.



Asaphus tyrannus, Murch., $\frac{1}{3}$.
Llandeilo; Bishop's Castle, &c.

Fig. 567.



Ogygia Buchii, Burm., $\frac{1}{3}$.
Syn. *Asaphus Buchii*, Brongn.
Builth, Radnorshire; Llandeilo,
Caermarthenshire.

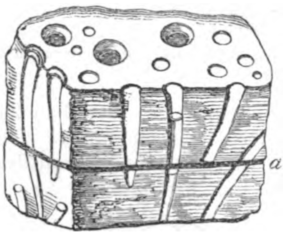
(p. 470) form a marked feature of the rich and varied Trilobitic fauna of this age.

Beneath the black slates above described of the Llandeilo formation, graptolites are still found in great variety and abundance, and the characteristic genera of shells and trilobites of the Lower Silurian rocks are still traceable downwards, in Shropshire, Cumberland, and North and South Wales, through a vast thickness of shaly beds, in some districts interstratified with trappean rocks of contemporaneous origin; these consist of tuffs and lavas, the tuffs being formed of such materials as are ejected from craters and deposited immediately on the bed of the ocean, or washed into it from the land. According to Professor Ramsay, their thickness is about 3,300 feet in North Wales, including those of the Lower Llandeilo about to be

described, and they also attain a great thickness in Pembrokeshire, in South Wales. The lavas are felspathic, and of porphyritic structure, and, according to the same authority, of an aggregate thickness of 2,500 feet.

Arenig or Stiper-stones Group (*Lower Llandeilo of Murchison*).—Next in the descending order, and forming the base of the series, are the shales and sandstones in which the quartzose rocks called Stiper-stones in Shropshire occur. Originally these Stiper-stones were only known as arenaceous quartzose strata in which no organic remains were conspicuous, except the tubular burrows of annelids (see fig. 568, *Arenicolites linearis*), which are remarkably common in the Lowest Silurian in Shropshire, the north-west Highlands of Scotland, and in the State of New York in America. They have already been alluded to as occurring by thousands in the white quartzose Lower Silurian strata unconformably overlying the Cambrian in the mountain of Queenaig in Sutherlandshire (see fig. 82, p. 91). I have seen similar burrows now made on the retiring of the tides in the sands of the Bristol Channel, near Minehead, by lobworms which are dug out by fishermen and used as bait. When the term Silurian was given by Sir R. Murchison, in 1835, to the whole series, he considered the Stiper-stones as the base of the Silurian system; but no fossil fauna had then been obtained, such as could alone enable the geologist to draw a line between this member of the series and the Llandeilo flags above, or the vast thickness of rock below which was seen to form the Longmynd hills, and was called 'unfossiliferous graywacke.' Professor Sedgwick had described, in 1843, strata now ascertained to be of the same age, as largely developed in the Arenig mountain in Merionethshire; and the Skiddaw slates in the Lake District of Cumberland, studied by the same author, were of corresponding date, though the number of fossils was, in both cases, too few for the determination of their true chronological relations. The subsequent researches of Messrs. Sedgwick and Harkness in Cumberland, and of Sir R. I. Murchison and the Government surveyors in Shropshire, have increased the species to more than sixty. These were examined by Mr. Salter, and shown in the third edition of 'Siluria' (p. 52, 1859) to be quite

Fig. 568.



Arenicolites linearis, Hall.
Arenig beds, Stiper-stones.
a. Parting between the beds, or planes of bedding.

distinct from the fossils of the overlying Llandeilo flags. Among these the *Obolella plumbea*, *Æglina binodosa*, *Ogygia Selwynii*, and *Didymograpsus geminus* (fig. 569), and *D. hirundo*, are characteristic.

Fig. 569.

Didymograpsus geminus, Hisinger, sp. Sweden.

But, although the species are distinct, most of the genera are the same as those which characterise the Silurian rocks above, and none of the characteristic primordial or Cambrain species, presently to be mentioned, are intermixed. The same may be said of a set of beds underlying the Arenig rocks at Ramsay Island and other places in the neighbourhood of St. David's. These beds, commonly called the Tremadoc beds, and presently to be described, present already 22 new species, chiefly Lamellibranchiata and Trilobites, which have only lately become known to us through the labours of Dr. Hicks.[6] This Arenig group may therefore be conveniently regarded as the base of the great Silurian system—a system which, by the thickness of its strata and the changes in animal life of which it contains the record, is more than equal in value to the Devonian, or Carboniferous, or other principal divisions, whether of primary or secondary date.

It would be unsafe to rely on the mere thickness of the strata, considered apart from the great fluctuations in organic life which took place between the era of the Llandeilo and that of the Ludlow formation, especially as the enormous pile of Silurian rocks observed in Great Britain (in Wales more particularly) is derived in great part from igneous action, and is not confined to the ordinary deposition of sediment from rivers or the waste of cliffs.

In volcanic archipelagoes, such as the Canaries, we see the most active of all known causes, aqueous and igneous, simultaneously at work to produce great results in a comparatively moderate lapse of time. The outpouring of repeated streams of lava—the showering down upon land and sea of volcanic ashes—the sweeping seaward of loose sand and cinders, or of rocks ground down to pebbles and sand, by rivers and torrents descending steeply-inclined channels—the undermining and eating away of long lines of sea-cliff exposed to the swell of a deep and open ocean—these operations combine to produce a considerable

[6] Trans. Brit. Assoc., 1866. Proc. Liverpool Geol. Soc., 1869.

volume of superimposed matter, without there being time for any extensive change of species. Nevertheless, there would seem to be a limit to the thickness of stony masses formed even under such favourable circumstances, for the analogy of tertiary volcanic regions lends no countenance to the notion that sedimentary and igneous rocks, 25,000, much less 45,000 feet thick, like those of Wales, could originate while one and the same fauna should continue to people the earth. If, then, we allow that about 25,000 feet of matter may be ascribed to one system, such as the Silurian, as above described, we may be prepared to discover in the next series of subjacent rocks a distinct assemblage of species, or even in great part of genera, of organic remains. Such appears to be the fact; and I shall therefore conclude with the Arenig beds my enumeration of the Silurian formations in Great Britain, and proceed to say something of their foreign equivalents, before treating of rocks older than the Silurian.

Silurian Strata of the Continent of Europe.—When we turn to the Continent of Europe, we discover the same ancient series occupying a wide area, but in no region as yet has it been observed to attain great thickness. Thus, in Norway and Sweden, the total thickness of strata of Silurian age is considerably less than 1,000 feet, although the representatives both of the Upper and Lower Silurian of England are not wanting there. In Russia the Silurian strata, so far as they are yet known, seem to be even of smaller vertical dimensions than in Scandinavia, and they appear to consist chiefly of the Llandovery group, or of a limestone containing *Pentamerus oblongus*, below which are strata with fossils corresponding to those of the Llandeilo beds of England. The lowest rock with organic remains yet discovered is 'the Ungulite or Obolus grit' of St. Petersburg, probably coeval with the Llandeilo flags of Wales.

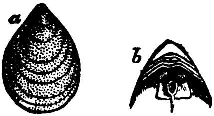
The shales and grits near St. Petersburg, above alluded to, contain green grains in their sandy layers, and are in a singularly unaltered state, taking into account their high antiquity. The prevailing brachiopods consist of the *Obolus* or Ungulite of Pander, also found in the Wenlock limestone of England, and a *Siphonotreta*, common to both the Upper and Lower Silurian of England (figs. 570, 571).

Among the green grains of the sandy strata above mentioned, Prof. Ehrenberg announced in 1854 his discovery of remains of foraminifera. These are casts of the cells; and amongst five or six forms three are considered by him as referable to existing genera (e.g. *Textularia*, *Rotalia*, and *Guttulina*).

In the year 1846, as before stated, M. Joachim Barrande, after ten years' exploration of Bohemia and after collecting more

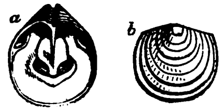
Shells of the lowest known Fossiliferous Beds in Russia.

Fig. 570.



Siphonotreta unguiculata, Eichwald, nat. size.
From the lowest Silurian Sandstone, 'Obolus grits,' of Petersburg.
a. Outside of perforated valve.
b. Interior of same, showing the termination of the foramen within (Davidson.)

Fig. 571.



Obolus Apollinis, Eichwald, nat. size.
From the same locality.
a. Interior of the large or ventral valve.
b. Exterior of the upper (dorsal) valve. (Davidson, 'Palæontograph, Monog.')

than a thousand species of fossils, had ascertained the existence in that country of three distinct faunas below the Devonian. To his first fauna, which was older than any then known in this country, he gave the name of Étage C; his two first stages A and B consisting of crystalline and metamorphic rocks and unfossiliferous schists. This Étage C or primordial zone proved afterwards to be the equivalent of the Upper Cambrian, to be described in the next chapter. The second fauna, Étage D, tallies with Murchison's Lower Silurian as originally defined by him when no fossils had been discovered below the Stiperstones. The third fauna, Étages E, F, G, agrees with the Upper Silurian of the same author. Barrande, without Government assistance, had undertaken single-handed the geological survey of Bohemia, the fossils previously obtained from that country having scarcely exceeded 20 in number, whereas he had already acquired in 1850 no less than 1,100 species—namely, 250 crustaceous (chiefly Trilobites), 250 cephalopods, 160 gasteropods and pteropods, 130 acephalous mollusks, 210 brachiopods, and 110 corals and other fossils.

Subsequent researches of M. Barrande have raised the number of cephalopods to 970 species and the Trilobites to nearly 400, while many of the other groups are almost doubled. So great is the number of cephalopods in this Silurian fauna of Bohemia that it might truly be characterised as the age of cephalopods.

Silurian Strata of the United States.—The Silurian formations can be advantageously studied in the States of New York, Ohio, and other regions north and south of the great Canadian lakes. Here they are often found, as in Russia, nearly in horizontal position, and are more rich in well-preserved fossils than in almost any spot in Europe. In the State of New York, where

the succession of the beds and their fossils have been most carefully worked out by the Government surveyors, the subdivisions given in the first column of the annexed list have been adopted.

Subdivisions of the Silurian Strata of New York. (Strata below the Oriskany Sandstone or base of the Devonian.)

New York Names.	British Equivalents.
1. Upper Pentamerus Limestone 2. Encrinal Limestone 3. Delthyris Shaly Limestone 4. Pentamerus and Tentaculite Limestones 5. Water Lime Group 6. Onondaga Salt Group 7. Niagara Group	Upper Silurian (or Ludlow and Wenlock Formations).
8. Clinton Group 9. Medina Sandstone 10. Oneida Conglomerate 11. Grey Sandstone	Beds of Passage, Llandovery Group.
12. Hudson River Group 13. Trenton Limestone 14. Black-River Limestone 15. Bird's-Eye Limestone 16. Chazy Limestone 17. Calciferous Sandstone	Lower Silurian or Caradoc and Bala, Llandeilo and Arenig Formations.

In the second column of the same table I have added the supposed British equivalents. All palæontologists, European and American, such as MM. de Verneuil, D. Sharpe, Prof. Hall, E. Billings, and others, who have entered upon this comparison, admit that there is a marked general correspondence in the succession of fossil forms, and even species, as we trace the organic remains downwards from the highest to the lowest beds; but it is impossible to parallel each minor subdivision.

That the Niagara Limestone, over which the river of that name is precipitated at the great cataract, together with its underlying shales, corresponds to the Wenlock limestone and shale of England, there can be no doubt. Among the species common to this formation in America and Europe are *Calymene, Blumenbachii, Homalonotus delphinocephalus* (fig. 549, p. 465), with several other trilobites; *Rhynchonella Wilsoni* (fig. 536, p. 459), and *Retzia cuneata; Orthis elegantula, Pentamerus galeatus,* with many more brachiopods; *Orthoceras annulatum,* among the cephalopodous shells; and *Favosites Gothlandica,* with other large corals.

The Clinton Group, containing *Pentamerus oblongus* and *Stricklandinia,* and related more nearly by its fossil species with

the beds above than with those below, is the equivalent of the Llandovery Group or beds of passage.

The Hudson River Group, and the Trenton Limestone, agree palæontologically with the Caradoc or Bala Group, containing in common with them several species of trilobites, such as *Asaphus* (*Isotelus*) *gigas*, *Trinucleus concentricus* (fig. 558, p. 470); and various shells, such as *Orthis striatula*, *Orthis biforata* (or *O. lynx*), *O. porcata* (*O. occidentalis* of Hall), and *Bellerophon bilobatus.* In the Trenton Limestone occurs *Murchisonia gracilis* (fig. 572), a fossil also common to the Llandeilo beds in England.

Fig. 572.

Murchisonia gracilis, Hall. Nat. size.
A fossil characteristic of the Trenton Limestone. The genus is common in Lower Silurian rocks.

Mr. D. Sharpe, in his report on the mollusca collected by me from these strata in North America,[7] concluded that the number of species common to the Silurian rocks on both sides of the Atlantic was between 30 and 40 per cent.; a result which, although no doubt liable to future modification, when a larger comparison shall have been made, proves, nevertheless, that many of the species had a wide geographical range. It seems that comparatively few of the gasteropods and lamellibranchiate bivalves of North America can be identified specifically with European fossils, while no less than two-fifths of the brachiopoda, of which my collection chiefly consisted, are the same. In explanation of these facts, it is suggested that most of the recent brachiopods (especially the orthidiform ones) are inhabitants of deep water, and that they may have had a wider geographical range than shells living near shore. The predominance of bivalve mollusca of this peculiar class has caused the Silurian period to be sometimes styled 'the age of brachiopods.'

In Canada, as in the State of New York, the Potsdam Sandstone underlies the above-mentioned calcareous rocks, but contains a different suite of fossils, as will be hereafter explained. In parts of the globe still more remote from Europe the Silurian strata have also been recognised, as in South America, Australia, and India. In all these regions the facies of the fauna, or the types of organic life, enable us to recognise the contemporaneous origin of the rocks; but the fossil species are distinct, showing that the old notion of a universal diffusion throughout the 'primæval seas' of one uniform specific fauna was quite unfounded, geographical provinces having evidently existed in the oldest as in the most modern times.

[7] Quart. Geol. Journ., vol. vi.

CHAPTER XXVII.

CAMBRIAN AND LAURENTIAN GROUPS.

Classification of the Cambrian group, and its equivalent in Bohemia—Upper Cambrian rocks—Tremadoc slates and their fossils—Lingula Flags—Lower Cambrian rocks—Menevian Beds—Longmynd group—Harlech grits, with large Trilobites—Llanberis slates—Cambrian rocks of Bohemia—Primordial zone of Barrande—Metamorphosis of Trilobites—Cambrian Rocks of Sweden and Norway—Cambrian Rocks of the United States and Canada—Potsdam sandstone—Huronian series—Laurentian group, upper and lower—*Eozoon Canadense*, oldest known fossil—Fundamental gneiss of Scotland.

CAMBRIAN GROUP.

THE characters of the Upper and Lower Silurian rocks were established so fully, both on stratigraphical and palæontological data, by Sir Roderick Murchison after five years' labour, in 1839, when his 'Silurian System' was published, that these formations could from that period be recognised and identified in all other parts of Europe and in North America, even in countries where most of the fossils differed specifically from those of the classical region in Britain, where they were first studied.

While Sir R. I. Murchison was exploring in 1833 in Shropshire and the borders of Wales the strata which in 1835 he first called Silurian, Professor Sedgwick was surveying the rocks of North Wales, which both these geologists considered at that period as of older date, and for which in 1836 Sedgwick proposed the name of 'Cambrian.' It was afterwards found that a large portion of the slaty rocks of North Wales which had been considered as more ancient than the Llandeilo beds and Stiper-stones before alluded to, were, in reality, not inferior in position to those Lower Silurian beds of Murchison, but merely extensive undulations of the same, bearing fossils identical in species, though these were generally rarer and less perfectly preserved, owing to the changes which the rocks had undergone from metamorphic action. To such rocks the term 'Cambrian' was no longer applicable, although it continued to be appropriate to strata inferior to the Stiper-stones, and which were older than those of the Lower Silurian group as originally

defined. It was not till 1846 that fossils were found in Wales in the Lingula flags, the place of which will be seen in the annexed table. By this time Barrande had already published an account of a rich collection of fossils which he had discovered in Bohemia, portions of which he recognised as of corresponding age with Murchison's Upper and Lower Silurian, while others were more ancient, to which he gave the name of 'Primordial,' for the fossils were sufficiently distinct to entitle the rocks to be referred to a new and earlier period. They consisted chiefly of trilobites of genera distinct from those occurring in the overlying Silurian formations. These peculiar genera were afterwards found in rocks holding a corresponding position in Wales, and I shall retain for them the term Cambrian, as recent discoveries in our own country seem to carry the first fauna of Barrande, or his primordial type, even into older strata than any which he found to be fossiliferous in Bohemia.

The term primordial was intended to express M. Barrande's own belief that the fossils of the rocks so called afforded evidence of the first appearance of vital phenomena on this planet, and that consequently no fossiliferous strata of older date would or could ever be discovered. The acceptance of such a nomenclature would seem to imply that we despaired of extending our discoveries of new and more ancient fossil groups at some future day when vast portions of the globe, hitherto unexplored, should have been thoroughly surveyed. Already the discovery of the Laurentian Eozoon in Canada, presently to be mentioned, discountenances such views.

The following table will show the succession of the strata in England and Wales which belong to the Cambrian group, or the fossiliferous rocks older than the Arenig or Lower Llandeilo rocks.

UPPER CAMBRIAN.

TREMADOC SLATES. (*Primordial of Barrande in part.*)
LINGULA FLAGS. *Primordial of Barrande.*

LOWER CAMBRIAN.

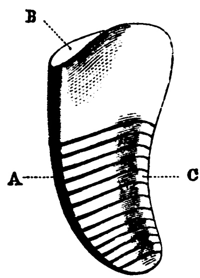
MENEVIAN BEDS. (*Primordial of Barrande.*)
LONGMYND GROUP { *a.* Harlech Grits.
b. Llanberis Slates.

UPPER CAMBRIAN.

Tremadoc Slates.—The Tremadoc slates of Sedgwick are more than 1,000 feet in thickness, and consist of dark earthy slates occurring near the little town of Tremadoc, situated on the north side of Cardigan Bay in Carnarvonshire. These grey rocks and slates were first examined by Sedgwick in 1831,

and were re-examined by him and described in 1846.[1] They were traced by their pisolitic ore from Tremadoc to Dolgelly, but no peculiar fossils were then observed in them, though some organic remains had been found in the underlying Lingula flags by Mr. Davis; 68 species of all classes have now, however, been found in the Tremadoc slates, thanks to the researches of Messrs. Salter, Homfray, Hicks, and Ash, and of these 60 are peculiar, only 4 passing up into higher strata, thus exhibiting a line of demarcation between the Silurian and Cambrian formations greater than any yet recognised in the Palæozoic series. We have already seen that in the Arenig or Stiper-stones group, where the species are distinct, the genera agree with Silurian types; but in these Tremadoc slates, where the species are also peculiar, there is about an equal admixture of Silurian types with those which Barrande has termed 'primordial.' Here, therefore, it may truly be said that we are entering upon a new domain of life in our retrospective survey of the past. The trilobites of new species, but of Lower Silurian genera, belong to *Ogygia*, *Asaphus*, and *Cheirurus*; whereas those belonging to primordial types, or Barrande's first fauna, as well as to the Lingula flags of Wales, comprise *Dikelocephalus*, *Cono-*

Fig. 573.



Cyrtoceras precox, Salt. mag.
Llandeilo and Tremadoc rocks, N. Wales.
a. Dorsal edge, place of siphuncle.
b. Aperture. *c.* Ventral edge.

Fig. 574.

Theca (*Cleidotheca*) *operculata*, nat. size.
Lower Tremadoc beds, Tremadoc.

coryphe (for genera see figs. 583 and 587),[2] *Olenus*, and *Angelina*. The genus Bellerophon is represented in the Tremadoc slates by species different to those found in the Lower Silurian: the Pteropods *Theca* (fig. 574) and *Conularia* range throughout these slates, but there are no Graptolites. The *Lingula* (*Lingulella*) *Davisii* ranges from the top to the bottom of the formation, and links it with the zone next to be described. The Tremadoc

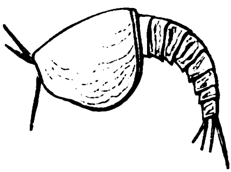
[1] Geol. Quart. Journ., vol. iii. p. 156.

[2] This genus has been substituted for Barrande's *Conocephalus*, as the latter term had been preoccupied by the entomologists.

beds were formerly supposed to be confined to a small part of North Wales, but more lately beds of the same age have been discovered and thoroughly investigated by Dr. Hicks at St. David's Promontory and Ramsey Island, South Wales. He states that they rest conformably on the Lingula flags, and usually graduate by insensible degrees into them.[3] Twelve species of Lamellibranchiata occur in the Tremadoc beds of Ramsey Island, and this is at present the earliest formation in which they are found. Two genera, *Glyptarca* and *Davidia*, are new. The Echinoderms are represented by a beautiful star-fish of the genus *Palasterina* and by an Encrinite of the genus *Dendrocrinus*.[4] Cephalopoda have not yet been found lower than this group, and only two peculiar species, *Cyrtoceras precox* (fig. 573) and *Orthoceras sericeum*, are known here.

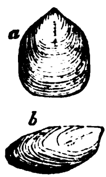
Lingula Flags.—Next below the Tremadoc slates in North Wales, lie micaceous flagstones and slates, in which in 1846 Mr. E. Davis discovered the *Lingula* (*Lingulella*) (fig. 576) named

Fig. 575.



Hymenocaris vermicauda, Salter.
A Phyllopod Crustacean.
½ natural size.

Fig. 576.



Lingulella Davisii, M'Coy.
a. ½ natural size.
b. Distorted by cleavage.

Fig. 577.

Olenus micrurus, Salter.
½ natural size.

'Lingula Flags' of Dolgelly, and Ffestiniog, N. Wales.

after him, and from which was derived the name of Lingula flags. These beds, which are paleontologically the equivalents of Barrande's primordial zone, are represented by more than 5,000 feet of strata, and have been studied chiefly in the neighbourhood of Dolgelly, Ffestiniog, and Portmadoc in North Wales, and also at St. David's in South Wales. They have yielded about 35 species of fossils, of which six only are common to the overlying Tremadoc rocks, but the two formations are closely allied by having several characteristic 'primordial' genera in common. *Dikelocephalus*, *Paradoxides*, *Olenus* (fig. 577), and *Conocoryphe* are prominent forms, as is also *Hymenocaris* (fig. 575), a genus of phyllopod crustacean entirely confined to the Lingula Flags. According to Mr. Belt, who has devoted much

[3] Hicks, Proc. Geol. Assoc., vol. iii. No. 3, 1873.
[4] Hicks, Quart. Geol. Journ., vol. xxix. p. 42.

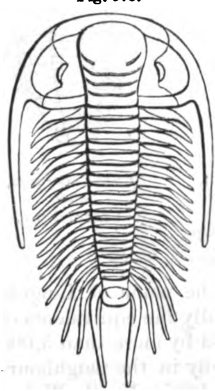
attention to these beds, there are already paleontological data for subdividing the Lingula Flags into three sections,[5] the Dolgelly, Ffestiniog, and Maentwrog groups.

In Merionethshire, according to Professor Ramsay, the Lingula Flags attain their greatest development; in Carnarvonshire, they thin out so as to have lost two-thirds of their thickness in eleven miles; while in Anglesea and on the Menai Straits both they and the Tremadoc beds are entirely absent, and the Lower Silurian rests directly on Lower Cambrian strata.

LOWER CAMBRIAN.

Menevian Beds.—Immediately beneath the Lingula Flags there occurs a series of dark grey and black flags and slates alternating at the upper part with some beds of sandstone, the whole reaching a thickness of from 500 to 600 feet. These beds were formerly classed, on purely lithological grounds, as the base of the Lingula Flags; but Messrs. Belt, Hicks, and Salter,[6] to whose exertions we owe almost all our knowledge of the fossils, have pointed out that the most characteristic genera found in them are quite unknown in the Lingula flags, while they possess many genera, such as *Microdiscus* and *Paradoxides*, characteristic of the underlying Longmynd Group. They therefore proposed to place them, and it seems to me with good reason, at the top of the Lower Cambrian under the term 'Menevian,' Menevia being the classical name of St. David's. The beds are well exhibited in the neighbourhood of St. David's in South Wales, and near Dolgelly and Maentwrog in North Wales. They are the equivalents of Étage C of Barrande's Primordial Zone. Fifty-two species have been found in them, and the group is altogether very rich in fossils for so early a period. Ten species are common to the overlying Lingula Flags, but none pass up to the Tremadoc beds. The trilobites are of large size; *Paradoxides Davidis* (see fig. 578), the largest trilobite known in Great Britain, 22 inches or nearly 2 feet long, is peculiar to the

Fig. 578.



Paradoxides Davidis, Salt.
$\frac{1}{10}$ nat. size.
Menevian beds,
St. David's and Dolgelly.

[5] Geol. Mag., vols. iv. and v., 1867 and 1868.

[6] British Association Report, 1865, 1866, 1868, and Quart. Geol. Journ., vols. xxi. xxv.

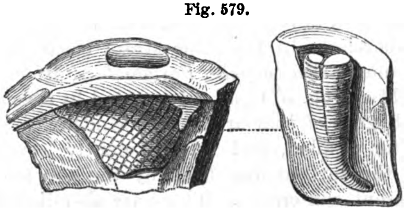
Menevian beds. By referring to the Bohemian trilobite of the same genus (fig. 582, p. 487), the reader will at once see how these fossils (though of such different dimensions) resemble each other in Bohemia and Wales; and other closely allied species from the two regions might be added, besides some which are common to both countries. The Swedish fauna, presently to be mentioned, will be found to be still more nearly connected with the Welsh Menevian. In all these countries there is an equally marked difference between the Cambrian fossils and those of the Upper and Lower Silurian rocks. The trilobite with the largest number of rings, *Erinnys venulosa*, occurs here in conjunction with *Agnostus* and *Microdiscus*, the two genera with the smallest number. Blind trilobites are also found as well as those which have the largest eyes, such as *Microdiscus* on the one hand, and *Anopolenus* on the other.

LONGMYND GROUP.

Older than the Menevian Beds are a thick series of olive green, purple, red and grey grits and conglomerates found in North and South Wales, Shropshire, and parts of Ireland and Scotland. They have been called by Professor Sedgwick the Longmynd or Bangor Group, comprising, first, the Harlech and Barmouth sandstones; and secondly, the Llanberis slates.

Harlech grits and Llanberis slates.—The sandstones of this period attain in the Longmynd hills a thickness of no less than 6,000 feet without any interposition of volcanic matter; in some places in Merionethshire they are still thicker. Until recently these rocks possessed but a very scanty fauna.

Fig. 579.



1 2

Histioderma Hibernica (Kin.). Oldhamia beds. Bray Head, Ireland.

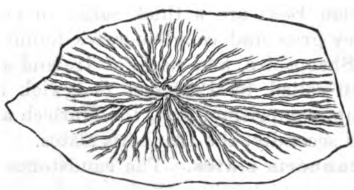
1. Showing opening of burrow, and tube with wrinklings or crossing ridges, probably produced by a tentacled sea worm or annelid.
2. Lower and curved extremity of tube with five transverse lines.

With the exception of five species of annelids brought to light by Mr. Salter in Shropshire, and Dr. Kinahan in Wicklow, and an obscure form of trilobite, *Palæopyge Ramsayi*,

they were supposed to be barren of organic remains. Now, however, through the labours of Mr. Hicks,[7] they have yielded at St. David's a rich fauna of trilobites, brachiopods, phyllopods, and pteropods, showing, together with other fossils, a by no means low series of organisms at this early period. Already the fauna amounts to 25 species referred to 17 genera; of these 12 genera and 8 species are common to the Menevian Group; 'a proportion,' says Mr. Hicks, 'far greater than we usually find between two groups so dissimilar in lithological characters and comprising so great a thickness of strata.'

A new genus of trilobite, called *Plutonia Sedgwickii* by Dr. Hicks, has been met with in the Harlech grits of St. David's.

Fig. 580.



Oldhamia radiata, Forbes.
Wicklow, Ireland.

Fig. 581.

Oldhamia antiqua, Forbes.
Wicklow, Ireland.

It is comparable in size to the large *Parodoxides Davidis* before mentioned, has well-developed eyes, and is covered all over with rough tubercles. In the same strata occur other genera of trilobites, namely, *Conocoryphe*, *Paradoxides*, *Microdiscus*, and the Pteropod *Theca* (fig. 574), all represented by species peculiar to the Harlech grits of that area. The sandstones of this formation are often rippled, and were evidently left dry at low tides, so that the surface was dried by the sun and made to shrink and present sun-cracks. There are also distinct impressions of raindrops on many surfaces, like those figured at p. 409. Fossils occur yet earlier in the Harlech group of St. David's in the lower Red Shales that immediately overlie the conglomerate and hornstone series. The only forms yet found are *Lingulella ferruginea*, *L. primæva*, and *Leperditia primæva*, and these constitute the earliest life (with the exception of

[7] Brit. Assoc. Report, 1868.

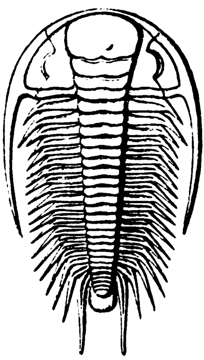
Eozoon, presently to be mentioned) yet met with. The succeeding 1,500 feet of greenish yellow and green-and-red sandstones have yielded no organic remains.

The slates of Llanberis and Penrhyn in Carnarvonshire, with their associated sandy strata, attain a great thickness, sometimes about 3,000 feet. They are perhaps not more ancient than the Harlech and Barmouth beds last mentioned, for they may represent the deposits of fine mud thrown down in the same sea, on the borders of which the sands above mentioned were accumulating. In some of these slaty rocks at Bray Head in Ireland, immediately opposite Anglesea and Carnarvon, two species of fossils have been found, to which the late Professor E. Forbes gave the name of *Oldhamia*. The nature of these organisms is still a matter of discussion among naturalists.

Cambrian rocks of Bohemia (*Primordial Zone of Barrande*).—We have already seen when treating of the Silurian strata of Bohemia, p. 481, that in the year 1846 Barrande gave the name of Étage C to the earliest fauna discovered by him in that country.

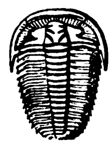
Fossils of the lowest Fossiliferous Beds in Bohemia, or 'Primordial Zone' of Barrande.

Fig. 582.



Paradoxides Bohemicus, Barr.
About ½ natural size.

Fig. 583.



Conocoryphe striata, Syn.
Conocephalus striatus, Emmrich.
½ natural size. Ginetz and Skrey.

Fig. 584.

Agnostus integer, Beyrich.
Nat. size and magnified.

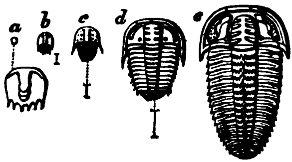
Fig. 585.

Agnostus Rex, Barr.
Nat. size, Skrey.

This Étage C or primordial zone is now proved to be the equivalent of those subdivisions of the Cambrian groups which have been above described under the names of Menevian and Lingula Flags. In it M. Barrande found in Bohemia trilobites of the genera *Paradoxides*, *Conocoryphe*, *Ellipsocephalus*, *Sao*, *Arionellus*, *Hydrocephalus*, and *Agnostus*. M. Barrande pointed out that these primordial trilobites have a peculiar facies of their

own, dependent on the multiplication of their thoracic segments and the diminution of their caudal shield or pygidium.

Fig. 586.



The small lines beneath indicate the true size. In the youngest state, *a*, no segments are visible; as the metamorphosis progresses, *b*, *c*, the body segments begin to be developed; in the stage *d* the eyes are introduced, but the facial sutures are not completed; at *e* the full-grown animal, half its true size, is shown.

Sao hirsuta, Barrande, in its various stages of growth.

One of the 'primordial' or Upper Cambrian Trilobites of the genus *Sao*, a form not found as yet elsewhere in the world, afforded M. Barrande a fine illustration of the metamorphosis of these creatures, for he traced them through no less than twenty stages of their development. A few of these changes have been selected for representation in the accompanying figures, that the reader may learn the gradual manner in which different segments of the body and the eyes make their appearance.

In Bohemia the primordial fauna of Barrande derived its importance exclusively from its numerous and peculiar trilobites. Besides these, however, the same ancient schists have yielded two genera of brachiopods, *Orthis* and *Orbicula*, a pteropod of the genus *Theca*, and four echinoderms of the Cystidean family.

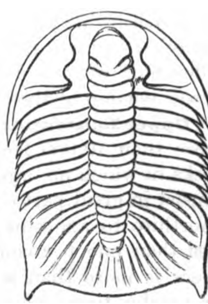
Cambrian of Sweden and Norway.—The Cambrian beds of Wales are represented in Sweden by strata, the fossils of which have been described by a most able naturalist, M. Angelin, in his 'Palæontologica Suecica (1852–4).' The 'alum-schists,' as they are called in Sweden, are horizontal argillaceous rocks which underlie conformably certain Lower Silurian strata in the mountain called Kinnekulle, south of the great Wener Lake in Sweden. These schists contain trilobites belonging to the genera *Paradoxides*, *Olenus*, *Agnostus*, and others, some of which present rudimentary forms, like the genus last mentioned, without eyes, and with the body segments scarcely developed, and others again have the number of segments excessively multiplied, as in *Paradoxides*. Such peculiarities agree with the characters of the crustaceans met with in the Cambrian strata of Wales, and Dr. Torell has recently found in Sweden the *Paradoxides Hicksii*, a well-known Lower Cambrian fossil.

At the base of the Cambrian strata in Sweden, which in the neighbourhood of Lake Wener are perfectly horizontal, lie ripple-marked quartzose sandstones with worm tracks and

annelid borings, like some of those found in the Harlech grits of the Longmynd. Among these are some which have been referred doubtfully to plants. These sandstones have been called in Sweden 'fucoid sandstones.' The whole thickness of the Cambrian rocks of Sweden does not exceed 300 feet from the equivalents of the Tremadoc beds to these sandstones, which last seem to correspond with the Longmynd and are regarded by Torell as older than any fossiliferous primordial rocks in Bohemia.

Cambrian of the United States and Canada (*Potsdam Sandstone*).—This formation, as we learn from Sir W. Logan, is 700 feet thick in Canada; the upper part consists of sandstone containing fucoids, and perforated by small vertical holes, which are very characteristic of the rock, and appear to have been made by annelids (*Scolithus linearis*). The lower portion is a conglomerate with quartz pebbles. I have seen the Potsdam sandstone on the banks of the St. Lawrence, and on the borders of Lake Champlain, where, as at Keesville, it is a white quartzose fine-grained grit, almost passing into quartzite. It is divided into horizontal ripple-marked beds, very like those of the Lingula Flags of Britain, and replete with a small round-shaped *Obolella*, in such numbers as to divide the rock intc parallel planes, in the same manner as do the scales of mica in some micaceous sandstones. Among the shells of this formation in Wisconsin are species of *Lingula* and *Orthis*, and several trilobites of the primordial genus *Dikelocephalus* (fig. 587). On the banks of the St. Lawrence, near Beauharnois and elsewhere, many fossil footprints have been observed on the surface of the rippled layers. They are supposed by Professor Owen to be the trails of more than one species of articulate animal, probably allied to the King Crab, or *Limulus*.

Fig. 587.



Dikelocephalus Minnesotensis, Dale Owen. ⅓ diameter. A large crustacean of the Olenoid group. Potsdam Sandstone. Falls of St. Croix, on the Upper Mississippi.

Recent investigations by the naturalists of the Canadian survey have rendered it certain that below the level of the Potsdam Sandstone there are slates and schists extending from New York to Newfoundland, occupied by a series of trilobitic forms similar in genera though not in species to those found in the European Upper Cambrian strata.

Huronian series.—Next below the Upper Cambrian occur strata called the Huronian by Sir W. Logan, which are of vast

thickness, consisting chiefly of a quartzite, with great masses of greenish chloritic slate, which sometimes include pebbles of crystalline rocks derived from the Laurentian formation, next to be described. Limestones are rare in this series, but one band of 300 feet in thickness has been traced for considerable distances to the north of Lake Huron. Beds of greenstone are intercalated conformably with the quartzose and argillaceous members of this series. No organic remains have yet been found in any of the beds, which are about 18,000 feet thick, and rest unconformably on the Laurentian rocks.

LAURENTIAN GROUP.

In the course of the geological survey carried on under the direction of Sir W. E. Logan, it has been shown that, northward of the river St. Lawrence, there is a vast series of crystalline rocks of gneiss, mica-schist, quartzite, and limestone, more than 30,000 feet in thickness, which have been called Laurentian, and which are already known to occupy an area of about 200,000 square miles. They are not only more ancient than the fossiliferous Cambrian formations above described, but are older than the Huronian last mentioned, and had undergone great disturbing movements before the Potsdam sandstone and the other 'primordial' or Cambrian rocks were formed. The older half of the Laurentian series is unconformable to the newer portion of the same.

Upper Laurentian or Labrador series.—The Upper Group, more than 10,000 feet thick, consists of stratified crystalline rocks in which no organic remains have yet been found. They consist in great part of felspars, which vary in composition from anorthite to andesine, or from those kinds in which there is less than one per cent. of potash and soda to those in which there is more than seven per cent. of these alkalies, the soda preponderating greatly. These felsparites sometimes form mountain masses almost without any admixture of other minerals; but at other times they include augite, which passes into hypersthene. They are often granitoid in structure. One of the varieties is the same as the iridescent labradorite rock of Labrador. The Adirondack Mountains in the State of New York are referred to the same series.

Lower Laurentian.—This formation, about 20,000 feet in thickness, is, as before stated, unconformable to that last mentioned; it consists in great part of gneiss of a reddish tint with orthoclase felspar. Beds of nearly pure quartz, from 400 to 600

feet thick, occur in some places. Hornblendic and micaceous schists are often interstratified, and beds of limestone usually crystalline. Beds of plumbago also occur, and it has naturally been conjectured that this pure carbon may have been of organic origin before it underwent metamorphism.

There are several of these limestones which have been traced to great distances, and one of them is from 700 to 1,500 feet thick. In the most massive of them Sir W. Logan observed in 1859 what he considered to be an organic body much resembling the Silurian fossil called *Stromatopora rugosa*. It had been obtained the year before by Mr. J. McCulloch at the Grand Calumet on the river Ottawa. This fossil was examined in 1864 by Dr. Dawson of Montreal, who detected in it, by aid of the microscope, the distinct structure of a Rhizopod or Foraminifer. Dr. Carpenter and Prof. T. Rupert Jones have since

Fig. 588.

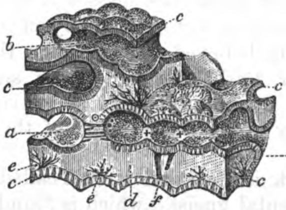
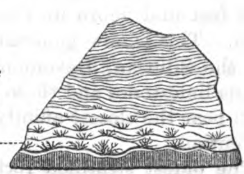


Fig. 589.



Eozoon Canadense, Daw. (after Carpenter). Oldest known organic body.

Fig. 588. *a*. Chambers of lower tier communicating at +, and separated from adjoining chambers at ⊙ by an intervening septum, traversed by passages. *b*. Chambers of an upper tier. *c*. Walls of the chambers, traversed by fine tubules. (These tubules pass with uniform parallelism from the inner to the outer surface, opening at regular distances from each other.) *d*. Intermediate skeleton, composed of homogeneous shell substance, traversed by stoloniferous passages (*f*), connecting the chambers of the two tiers. *e*. Canal system in intermediate skeleton, showing the arborescent sarcodic prolongations. (Fig. 589 shows these bodies in a decalcified state.) *f*. Stoloniferous passages.

Fig. 589. Decalcified portion of natural rock, showing *canal system* and the several layers; the acuteness of the planes prevents more than one or two parallel tiers being observed. Natural size.

confirmed this opinion, comparing the structure to that of the well-known nummulite. It appears to have grown one layer over another, and to have formed reefs of limestone as do the living coral-building polyp animals. Parts of the original skeleton, consisting of carbonate of lime, are still preserved; while certain interspaces in the calcareous fossil have been filled up with serpentine and white augite. On this oldest of known organic remains Dr. Dawson has conferred the name of *Eozoon Canadense* (see figs. 588, 589); its antiquity is such that the distance of time which separated it from the Upper Cambrian period,

or that of the Potsdam sandstone, may, says Sir W. Logan, be equal to the time which elapsed between the Potsdam sandstone and the nummulitic limestones of the Tertiary period. The Laurentian and Huronian rocks united are about 50,000 feet in thickness, and the Lower Laurentian was disturbed before the newer series was deposited. We may naturally expect that other proofs of unconformability will hereafter be detected at more than one point in so vast a succession of strata.

The mineral character of the Upper Laurentian differs, as we have seen, from that of the Lower, and the pebbles of gneiss in the Huronian conglomerates are thought to prove that the Laurentian strata were already in a metamorphic state before they were broken up to supply materials for the Huronian. Even if we had not discovered the Eozoon, we might fairly have inferred from analogy that as the quartzites were once beds of sand, and the gneiss and mica-schist derived from shales and argillaceous sandstones, so the calcareous masses from 400 to 1,000 feet and more in thickness were originally of organic origin. This is now generally believed to have been the case with the Silurian, Devonian, Carboniferous, Oolitic, and Cretaceous limestones and those nummulitic rocks of tertiary date which bear the closest affinity to the Eozoon reefs of the Lower Laurentian.

The oldest stratified rock in Scotland is that called by Sir R. Murchison 'the fundamental gneiss,' which is found in the north-west of Ross-shire, and in Sutherlandshire (see fig. 82, p. 89), and forms the whole of the adjoining island of Lewis, in the Hebrides. It has a strike from north-west to south-east, nearly at right angles to the metamorphic strata of the Grampians. On this Laurentian gneiss, in parts of the Western Highlands, the Cambrian and metamorphic Silurian rocks rest unconformably. It seems highly probable that this ancient gneiss of Scotland may correspond in date with part of the great Laurentian group of North America.

[The central axis of the Malvern chain consists of stratified but contorted schists, on which rest unconformably sandstones of Cambrian age. Mr. Hicks has also described a series of rocks underlying the Menevian beds in Pembrokeshire, which are apparently of sedimentary and volcanic origin. In the entire absence of organic remains, it is not possible to correlate these detached fragments with any particular member of the pre-Cambrian series on the other side of the Atlantic.]

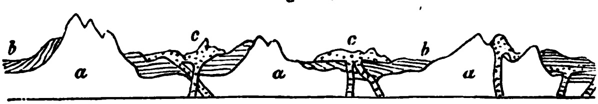
CHAPTER XXVIII.

VOLCANIC ROCKS.

External form, structure, and origin of volcanic mountains—Cones and craters—Hypothesis of 'elevation craters' considered—Trap rocks—Name whence derived—Minerals most abundant in volcanic rocks—Table of the analysis of minerals in the Volcanic and Hypogene rocks—Similar minerals in meteorites—Theory of Isomorphism—Basaltic rocks—Trachytic rocks—Special forms of structure—The columnar and globular forms—Trap dikes and veins—Alteration of rocks by volcanic dikes—Conversion of chalk into marble—Intrusion of trap between strata—Relation of trappean rocks to the products of active volcanos.

THE aqueous or fossiliferous rocks having now been described, we have next to examine those which may be called volcanic, in the most extended sense of that term. Suppose *a a* in the annexed diagram to represent the crystalline formations, such

Fig. 590.



a. Hypogene formations, stratified and unstratified.
b. Aqueous formations. *c.* Volcanic rocks.

as the granitic and metamorphic; *b b* the fossiliferous strata; and *c c* the volcanic rocks. These last are sometimes found, as was explained in the first chapter, breaking through *a* and *b*, sometimes overlying both, and occasionally alternating with the strata *b b*.

External form, structure, and origin of volcanic mountains.—The origin of volcanic cones with crater-shaped summits has been explained in the 'Principles of Geology' (chaps. xxiii. to xxvii.), where Vesuvius, Etna, Santorin, and Barren Island are described. The more ancient portions of those mountains or islands, formed long before the times of history, exhibit the same external features and internal structure which belong to most of the extinct volcanos of still higher antiquity; and these last have evidently been due to a complicated series of operations, varied in kind according to circumstances; as, for example, whether the accumulation took place above or below the level of the sea, whether the lava issued from one or several

contiguous vents; and lastly, whether the products of fusion in the subterranean regions contain more or less silica, alumina, potash, soda, lime, oxides of iron, and other ingredients. We are best acquainted with the effects of eruptions above water, or those called subaërial or supramarine; yet the products even of these are arranged in so many ways that their interpretation has given rise to a variety of contradictory opinions, some of which will have to be considered in this chapter.

Cones and Craters.—In regions where the eruption of volcanic matter has taken place in the open air, and where the surface has never since been subjected to great aqueous denudation, cones and craters constitute the most striking peculiarity of this class of formations. Many hundreds of these cones are seen in Central France, in the ancient provinces of Auvergne, Velay, and Vivarais, where they observe, for the most part, a linear arrangement, and form chains of hills. Although none of the eruptions have happened within the historical era, the streams of lava may still be traced distinctly descending from many of the craters, and following the lowest levels of the existing valleys. The origin of the cone and crater-shaped hill is well understood, the growth of many having been watched during volcanic eruptions. A chasm or fissure first opens in the earth, from which great volumes of steam are evolved. The explosions are so violent as to splinter the rocks in which the volcanic vent is opened, and hurl up into the air fragments of broken stone, parts of which are shivered into minute atoms. At the same time liquefied stone or *lava* usually ascends through the chimney or vent by which the gases make their escape. Although extremely heavy, this lava is forced up by the expansive power of entangled gaseous fluids, chiefly steam or aqueous vapour, exactly in the same manner as water is made to boil over the edge of a vessel when steam has been generated at the bottom by heat. Large quantities of the lava are also shot up into the air, where it separates into fragments and acquires a spongy texture by the sudden enlargement of the included gases, and thus forms *scoriæ*, other portions being reduced to an impalpable powder, or dust. The showering down of the various ejected materials round the orifice of eruption gives rise to a conical mound, in which the successive envelopes of sand and scoriæ form layers, dipping on all sides from a central axis. In the meantime a hollow, called a *crater*, has been kept open in the middle of the mound by the continued passage upwards of steam and other gaseous fluids. The lava sometimes flows over the edge of the crater, and thus thickens and strengthens the sides of the cone; but sometimes it breaks down the cone on

one side (see fig. 591), and often it flows out from a fissure at the base of the hill, or at some distance from its base.

Fig. 591.

Part of the chain of extinct volcanos called the Monts Dôme, Auvergne. (Scrope.)

Some geologists had erroneously supposed, from observations made on recent cones of eruption, that lava which consolidates on steep slopes is always of a scoriaceous or vesicular structure, and never of that compact texture which we find in those rocks which are usually termed 'trappean.' Misled by this theory, they have gone so far as to believe that if melted matter has originally descended a slope at an angle exceeding four or five degrees, it never on cooling acquires a stony compact texture. Consequently, whenever they found in a volcanic mountain sheets of stony materials inclined at angles of from 5° to 20° or even more than 30°, they thought themselves warranted in assuming that such rocks had been originally horizontal, or very slightly inclined, and had acquired their high inclination by subsequent upheaval. To such dome-shaped mountains with a cavity in the middle, and with the inclined beds having what was called a quâquâversal dip or a slope outwards on all sides, they gave the name of 'Elevation craters.'

As the late Leopold von Buch, the author of this theory, had selected the Isle of Palma, one of the Canaries, as a typical illustration of this form of volcanic mountain, I visited that island in 1854, in company with my friend Mr. Hartung, and I satisfied myself that it owes its origin to a series of eruptions of the same nature as those which formed the minor cones, already alluded to. In some of the more ancient or Miocene volcanic mountains, such as Mont Dore and Cantal in Central France, the mode of origin by upheaval as above described is attributed to those dome-shaped masses, whether they possess or not a great central cavity as in Palma. Where this cavity is present, it has probably been due to one or more great explosions similar to that which destroyed a great part of ancient Vesuvius in the time of Pliny. Similar paroxysmal catastrophes have caused in historical times the truncation on a grand scale of some large cones in Java and elsewhere.[1]

[1] Principles, vol. ii. pp. 56 and 145.

Among the objections which may be considered as fatal to von Buch's doctrine of upheaval in these cases I may state that a series of volcanic formations, extending over an area six or seven miles in its shortest diameter, as in Palma, could not be accumulated in the form of lavas, tuffs, and volcanic breccias or agglomerates without producing a mountain as lofty as that which they now constitute. But assuming that they were first horizontal, and then lifted up by a force acting most powerfully in the centre and tilting the beds on all sides, a central crater having been formed by explosion or by a chasm opening in the middle, where the continuity of the rocks was interrupted, we should have a right to expect that the chief ravines or valleys would open towards the central cavity, instead of which the rim of the great crater in Palma and other similar ancient volcanos is entire for more than three parts of the whole circumference.

If dikes are seen in the precipices surrounding such craters or central cavities, they certainly imply rents which were filled up with liquid matter. But none of the dislocations producing such rents can have belonged to the supposed period of terminal and paroxysmal upheaval, for had a great central crater been already formed before they originated, or at the time when they took place, the melted matter, instead of filling the narrow vents, would have flowed down into the bottom of the cavity, and would have obliterated it to a certain extent. Making due allowance for the quantity of matter removed by subaërial denudation in volcanic mountains of high antiquity, and for the grand explosions which are known to have caused truncation in active volcanos, there is no reason for calling in the violent hypothesis of elevation craters to explain the structure of such mountains as Teneriffe, the Grand Canary, Palma, or those of Central France, Etna, or Vesuvius, all of which I have examined. With regard to Etna, I have shown, from observations made by me in 1857, that modern lavas, several of them of known date, have formed continuous beds of compact stone even on slopes of 15, 36, and 38 degrees, and, in the case of the lava of 1852, more than 40 degrees. The thickness of these tabular layers varies from 1½ foot to 26 feet. At the same time the relations of these lava-streams to the surrounding rocks, and of their scoriaceous and compact portions to one another, are such as to preclude the possibility of a change of inclination having taken place subsequently to their solidification.[2]

Nomenclature of Volcanic rocks.—When geologists first began to examine attentively the structure of the northern and western parts of Europe, they were almost entirely ignorant of

[2] Memoir on Mount Etna, Phil. Trans. 1858.

the phenomena of existing volcanos. They found certain rocks, for the most part without stratification, and of a peculiar mineral composition, to which they gave different names, such as basalt, greenstone, porphyry, trap, tuff, and amygdaloid. All these, which were recognised as belonging to one family, were called 'trap' by Bergmann, from *trappa*, Swedish for a flight of steps —a name since adopted very generally into the nomenclature of the science; for it was observed that many rocks of this class occurred in great tabular masses of unequal extent, so as to form a succession of terraces or steps.

By degrees familiarity with the products of active volcanos convinced geologists more and more that they were identical with the trappean rocks. In every stream of modern lava there is some variation in character and composition; and even where no important difference can be recognised in the proportions of silica, alumina, lime, potash, iron, and other materials, the minerals which result from their combination are often not the same, for reasons which we are as yet unable to explain. The difference also of the lavas poured out from the same mountain at two distinct periods, especially in the proportion of silica which they contain, is often so great as to give rise to rocks which are regarded as forming distinct families, although there may be every intermediate gradation between the two extremes, and although some rocks, forming a transition from the one class to the other, may often be so abundant as to demand special names. Rocks containing an excess of silica (from 60 to 80 per cent.) are termed by many petrologists *acid* rocks, while those which, on the contrary, contain a small proportion of silica (from 45 to 55 per cent.) and a large proportion of the bases lime, potash, magnesia, oxide of iron, &c., are termed *basic*. I do not, however, adopt these terms, as they are founded on distinctions about which chemists are not agreed, and the term *acid* has unfortunately a meaning quite different to the technical one proposed, while on the other hand the terms trachytic (as synonymous with acid) and basaltic (as synonymous with basic) appear to me to answer all practical purposes and to be far more intelligible to the ordinary student. The different species of rocks included under these two heads might be multiplied indefinitely, and I can only afford space to name a few of the principal ones, about the composition and aspect of which there is the least discordance of opinion.

Minerals most abundant in volcanic rocks.—The minerals which form the chief constituents of these igneous rocks are few in number. Next to quartz, which is nearly pure silica or silicic acid, the most important are those silicates commonly classed

Analysis of Minerals most abundant in the Volcanic and Hypogene Rocks.

	Silica	Alumina	Sesquioxide of Iron	Protoxides of Iron and Manganese	Lime	Magnesia	Potash	Soda	Other Constituents	Specific Gravity
THE QUARTZ GROUP.										
QUARTZ	100·0	..	..	..	...	...	...	...	...	2·6
TRIDYMITE	100·0	..	..	..	...	...	...	...	...	2·3
THE FELSPAR GROUP.										
ORTHOCLASE. Carlsbad, in granite (Bulk).	65·23	18·26	0·27	...	trace	...	14·66	1·45	..	2·55
—— Sanidine, Drachenfels, in trachyte (Rammelsberg).	65·87	18·53	...	...	0·95	0·39	10·32	3·42	W. 0·44	
ALBITE. Arendal, in granite (G. Rose)	68·46	19·30	...	0·28	0·68	...	...	11·27	...	2·61
OLIGOCLASE. Ytterby, in granite (Berzelius).	61·55	23·80	...	...	3·18	0·80	0·38	9·67	...	2·65
—— Teneriffe, in trachyte (Deville)	61·55	22·03	...	...	2·81	0·47	3·44	7·74	...	2·59
LABRADORITE. Hitteroe, in Labrador-Rock (Waage).	51·39	29·42	2·90	...	9·44	0·37	1·10	5·63	W. 0·71	2·72
—— Iceland, in volcanic (Damour)	52·17	29·22	1·90	...	13·11	...	.	3·40	...	2·71
ANORTHITE. Harzburg, in diorite (Streng).	45·37	34·81	0·59	...	16·52	0·83	0·40	1·45	W. 0·87	2·74
—— Hecla, in volcanic (Waltershausen)	45·14	32·10	2·03	0·78	18·32	...	0·22	1·06	...	
LEUCITE. Vesuvius, 1811, in lava (Rammelsberg).	56·10	23·22	...	...	...	...	20·59	0·57	...	2·48
NEPHELINE. Miask, in miascite (Scheerer).	44·30	33·25	0·82	...	0·32	0·07	5·82	16·02	...	2·59
—— Vesuvius, in volcanic (Arfvedson)	44·11	33·73	...	...	...	...	...	20·46	W. 0·62	2·60
THE MICA GROUP.										
MUSCOVITE. Finland, in granite (Rose)	46·36	36·80	4·53	...	...	...	9·22	...	F. 0·67 W. 1·84	2·90
LEPIDOLITE. Cornwall, in granite (Regnault).	52·40	26·80	...	1·50	...	...	9·14	...	F. 4·18 Li. 4·85	2·90
BIOTITE. Bodenmais (V. Kobell)	40·86	15·13	13·00	...	...	22·00	8·83	...	W. 0·44	2·70
—— Vesuvius, in volcanic (Chodnef)	40·91	17·71	11·02	...	0·30	19·04	9·96	...		2·75
PHLOGOPITE. New York, in metam. limestone (Rammelsberg).	41·96	13·47	...	2·67	0·34	27·12	9·37	...	F. 2·93 W. 0·60	2·81
MARGARITE. Naxos (Smith)	30·02	49·52	1·65	...	10·82	0·48	1·25		W. 5·55	2·99
CHLORITE. Dauphiny (Marignac)	26·88	17·52	29·76	...	...	13·84	...	...	W. 11·33	2·87
RIPIDOLITE. Pyrenees (Delesse)	32·10	18·50	...	0·06	...	36·70	...	...	W. 12·10	2·61
TALC. Zillerthal (Delesse)	63·00	...	...	trace	...	33·60	...	...	W. 3·40	2·68
THE AMPHIBOLE AND PYROXENE GROUP.										
TREMOLITE. St. Gothard (Rammelsberg).	58·55	...	...	...	13·90	26·63	...	...	F.W. 0·34	2·93
ACTINOLITE. Arendal, in granite (Rammelsberg).	56·77	0·97	...	5·88	13·56	21·48	...	...	W. 2·20	3·02
HORNBLENDE. Faymont, in diorite (Deville).	41·99	11·66	...	22·22	9·55	12·59	...	1·02	W. 1·47	3·20
—— Etna, in volcanic (Waltershausen)	40·91	13·68	...	17·49	13·44	13·19	...	...	W. 0·85	3·21
URALITE. Ural (Rammelsberg)	50·75	5·65	...	17·27	11·59	12·28	...	...	W. 1·80	3·14
AUGITE. Bohemia, in dolerite (Rammelsberg).	51·12	3·38	0·95	8·08	23·54	12·82	...	...	...	3·36
—— Vesuvius, in lava of 1858 (Rammelsberg).	49·61	4·42	...	9·08	22·83	14·22	...	...	...	3·25
DIALLAGE. Harz, in Gabbro (Rammelsberg).	52·00	3·10	...	9·36	16·29	18·51	...	...	W. 1·10	3·23
HYPERSTHENE. Labrador, in Labrador-Rock (Damour).	51·36	0·37	...	22·59	3·09	21·31	...	...	...	3·39
BRONZITE. Greenland (V. Kobell)	58·00	1·33	11·14	...	...	29·66	...	...	...	3·20
OLIVINE. Carlsbad, in basalt (Rammelsberg).	39·34	...	...	14·85	...	45·81	...	...	...	3·40
—— Mount Somma, in volcanic (Walmstedt).	40·08	0·18	...	15·74	...	44·22	...	...	...	3·33

In the last column but one of the above table the following signs are used: F. Fluorine; Li. Lithia; W. Loss on igniting the mineral, in most instances only water.

under the several heads of felspar, mica, hornblende or augite, and olivine. In the annexed table, in drawing up which I have received the able assistance of Mr. David Forbes, the chemical analysis of these minerals and their varieties is shown, and he has added the specific gravity of the different mineral species, the geological application of which in determining the rocks formed by these minerals will be explained in the sequel (p. 503).

It will be observed that many minerals are omitted from this table which, even if they are of common occurrence, are more to be regarded as accessory than as essential components of the rocks in which they are found.[3] Such are, for example, Garnet, Epidote, Tourmaline, Idocrase, Andalusite, Scapolite, the various Zeolites, and several other silicates of somewhat rarer occurrence. Magnetite, Titanoferrite, and Iron-pyrites also occur as normal constituents of various igneous rocks, although in comparatively small amount, as also Apatite, or phosphate of lime. The other salts of lime, including its carbonate or calcite, although often met with, are invariably products of secondary chemical action.

The Zeolites, above mentioned, so named from the manner in which they froth up under the blow-pipe and melt into a glass, differ in their chemical composition from all the other mineral constituents of volcanic rocks, since they are hydrated silicates containing from 10 to 25 per cent. of water. They abound in some trappean rocks and ancient lavas, where they fill up vesicular cavities and interstices in the substance of the rocks, but are rarely found in any quantity in recent lavas ; in most cases they are to be regarded as secondary products formed by the action of water on the other constituents of the rocks. Amongst them the species Analcime, Stilbite, Natrolite, and Chabazite may be mentioned as of most common occurrence.

Quartz group.—The microscope has shown that pure quartz is oftener present in lavas than was formerly supposed. It had been argued that the quartz in granite, having a specific gravity of 2·6, was not of purely igneous origin, because the silica resulting from fusion in the laboratory has only a specific gravity of 2·3. But Mr. David Forbes has ascertained that the free quartz in trachytes which are known to have flowed as lava, has the same specific gravity as the ordinary quartz of granite, and the recent researches of Vom Rath and others prove that the mineral Tridymite, which is crystallised silica of sp. gr. 2·3 (see Table, p. 498), is of common occurrence in the volcanic rocks of Mexico, Auvergne, the Rhine, and elsewhere, although hitherto entirely overlooked.

[3] For analyses of these minerals see the Mineralogies of Dana and Bristow.

Felspar group.—In the Felspar group (Table, p. 498) the five mineral species most commonly met with as rock constituents are: 1. Orthoclase, often called common or potash-felspar. 2. Albite or soda-felspar, a mineral which plays a more subordinate part than was formerly supposed, this name having been given to much which has since been proved to be Oligoclase. 3. Oligoclase, or soda-lime-felspar, in which soda is present in much larger proportion than lime, and of which mineral andesite or andesine is considered to be a variety. 4. Labradorite, or lime-soda-felspar, in which the proportions of lime and soda are the reverse of what they are in Oligoclase. 5. Anorthite or lime-felspar. The three first-mentioned felspars are most common in the trachytic rocks; the two latter, on the other hand, are especially characteristic of rocks of the basaltic type.

In employing such terms as potash-felspar, &c., it must, however, always be borne in mind that it is only intended to direct attention to the predominant alkali or alkaline earth in the mineral, not to assert the absence of the others, which in most cases will be found to be present in minor quantity. Thus potash-felspar (orthoclase) almost always contains a little soda, and often traces of lime or magnesia; and in like manner with the others. The terms 'glassy' and 'compact' felspars only refer to structure, and not to species or composition: the student should be prepared to meet with any of the above felspars in either of these conditions: the so-called 'compact felspar' is also very commonly found to be an admixture of more than one felspar species, and frequently also contains quartz and other extraneous mineral matter only to be detected by the microscope. In examining the felspars contained in rocks it is also necessary to bear in mind the changes in lustre and colour, the result of incipient decomposition, to which all the varieties are more or less liable.

Felspars when arranged according to their system of crystallisation are *monoclinic*, having one axis obliquely inclined, or *triclinic*, having the three axes all obliquely inclined to each other. If arranged with reference to their cleavage they are *orthoclastic*, the fracture taking place always at a right angle, or *plagioclastic*, in which the cleavages are oblique to one another. Orthoclase is orthoclastic and monoclinic, all the other felspars are plagioclastic and triclinic. The latter group may often be recognised by the presence of fine parallel striæ, produced by the repeatedly twinned forms which characterise their imperfective junction of the crystals where they blend in each other.

Minerals in meteorites.—That species of the Felspar Group

which is called Anorthite has been shown by Rammelsberg to occur in a meteoric stone, and his analysis proves it to be almost identical in its chemical proportions with the same mineral in the lavas of modern volcanos. So also Bronzite (Enstatite) and Olivine have been met with in meteorites and shown by analysis to come remarkably near to these minerals in ordinary rocks.

Mica group.—With regard to the micas, the four principal species (Table, p. 498) all contain potash in nearly the same proportion, but differ greatly in the proportion and nature of their other ingredients. Muscovite is often called common or potash mica; Lepidolite is characterised by containing lithia in addition; Biotite contains a large amount of magnesia and oxide of iron; whilst Phlogopite contains still more of the former substance. In rocks containing quartz, muscovite or lepidolite are most common. The mica in recent volcanic rocks, gabbros, and diorites is usually Biotite, whilst that so common in metamorphic limestones is usually, if not always, Phlogopite.

Amphibole and Pyroxene group.—The minerals included in the table under the Amphibole and Pyroxene group differ somewhat in their crystalline form, though they all belong to the monoclinic system. Amphibole is a general name for all the different varieties of Hornblende, Actinolite, Tremolite, &c.; while Pyroxene may be considered to include Augite, Diallage, Malacolite, Sahlite, Diopside, Hypersthene, Bronzite, &c. The two divisions are so much allied in chemical composition and crystallographic characters, and blend so completely one into the other in Uralite (see p. 498), that it is perhaps best to unite them in one group.

Theory of Isomorphism.—The history of the changes of opinion on this point is curious and instructive. Werner first distinguished augite from hornblende; and his proposal to separate them obtained afterwards the sanction of Haüy, Mohs, and other celebrated mineralogists. It was agreed that the form of the crystals of the two species was different, and also their structure, as shown by *cleavage*, that is to say, by breaking or cleaving the mineral with a chisel, or a blow of the hammer, in the direction in which it yields most readily. It was also found by analysis that augite usually contained more lime, less alumina, and no fluoric acid; which last, though not always found in hornblende, often enters into its composition in minute quantity. In addition to these characters, it was remarked as a geological fact, that augite and hornblende are very rarely associated together in the same rock, augite being present in rocks in which there is but little silica such as Dolerite and Basalt, and hornblende occurring where silica is in excess

as in Granite and Syenite. It was also found that in the crystalline slags of furnaces, augitic forms were frequent, the hornblendic entirely absent; hence it was conjectured that hornblende might be the result of slow, and augite of rapid cooling. This view was confirmed by the fact, that Mitscherlich and Berthier were able to make augite artificially, but could never succeed in forming hornblende. Lastly, Gustavus Rose fused a mass of hornblende in a porcelain furnace, and found that it did not, on cooling, assume its previous shape, but invariably took that of augite. The same mineralogist observed certain crystals called Uralite (see Table, p. 498) in rocks from Siberia which possessed the cleavage and chemical composition of hornblende, while they had the external form of augite.

If, from these data, it is inferred that the same substance may assume the crystalline forms of hornblende or augite indifferently, according to the more or less rapid cooling of the melted mass, it is nevertheless certain that the variety commonly called augite, and recognised by a peculiar crystalline form, has usually more lime in it, and less alumina, than that called hornblende, although the quantities of these elements do not seem to be always the same. Unquestionably the facts and experiments above mentioned show the very near affinity of hornblende and augite; but even the convertibility of one into the other, by melting and recrystallising, does not perhaps demonstrate their absolute identity. For there is often some portion of the materials in a crystal which are not in perfect chemical combination with the rest. Carbonate of lime, for example, sometimes carries with it a considerable quantity of silica into its own form of crystal, the silica being mechanically mixed as sand, and yet not preventing the carbonate of lime from assuming the form proper to it. This is an extreme case, but in many others some one or more of the ingredients in a crystal may be excluded from perfect chemical union; and after fusion, when the mass recrystallises, the same elements may combine perfectly or in new proportions, and thus a new mineral may be produced. Or some one of the gaseous elements of the atmosphere, the oxygen for example, may, before the melted matter reconsolidates, have combined with some one or more of the component elements.

The different quantity of the impurities or the refuse above alluded to, which may occur in all but the most transparent and perfect crystals, may partly explain the discordant results at which experienced chemists have arrived in their analysis of the same mineral. For the reader will often find that crystals of a mineral determined to be the same by physical characters,

crystalline form, and optical properties, have been declared by skilful analysts to be composed of distinct elements. This disagreement seemed at first subversive of the atomic theory, or the doctrine that there is a fixed and constant relation between the crystalline form and structure of a mineral and its chemical composition. The apparent anomaly, however, which threatened to throw the whole science of mineralogy into confusion, was reconciled to fixed principles by the discoveries of Professor Mitscherlich at Berlin, who ascertained that the composition of the minerals which had appeared so variable was governed by a general law, to which he gave the name of *isomorphism* (from ισος, *isos*, equal, and μορφη, *morphe*, form). According to this law, the ingredients of a given species of mineral are not absolutely fixed as to their kind and quality; but one ingredient may be replaced by an equivalent portion of some other ingredient having analogous chemical and crystalline properties. Thus, in augite, the lime may be in part replaced by portions of protoxide of iron, or of manganese, while the form of the crystal, and the angle of its cleavage planes, remain the same. These vicarious substitutions, however, of particular elements cannot go beyond certain defined limits.

Basaltic Rocks.—The two principal families of trappean or volcanic rocks are the basalts and the trachytes, which differ chiefly from each other in the quantity of silica which they contain. The basaltic rocks are comparatively poor in silica, containing less than 55 per cent. of that mineral, and seldom any in a separate state or as free quartz, apart from the rest of the matrix. They contain a larger proportion of lime and magnesia than the trachytes, so that they are heavier independently of the frequent presence of the oxides of iron, which in some cases form a very large percentage of the whole mass. Abich has therefore proposed that we should ascertain the specific gravity of these rocks, in order to appreciate their composition in cases where it is impossible to separate their component minerals. Thus, basalt from Staffa containing 47·80 per cent. of silica has a specific gravity of 2·95; whereas trachyte, which has 66 per cent. of silica, has a sp. gr. of only 2·68; porphyritic trachyte, containing 69 per cent. of silica, a sp. gr. of only 2·58. If we then take a rock of intermediate composition, such as that prevailing in the Peak of Teneriffe, which Abich calls Trachyte-dolerite, its proportion of silica being intermediate, or 58 per cent., it has a specific gravity of 2·78, or more than trachyte, and less than basalt.[4]

Basalt.—The different varieties of this rock are distinguished by the names of basalts, anamesites, and dolerites, names

[4] Dr. Daubeny on Volcanos, 2nd ed., pp. 14, 15.

which, however, only denote differences in texture without implying any difference in mineral or chemical composition: the term *Basalt* being used only when the rock is compact, amorphous, and often semivitreous in texture and when it breaks with a perfect conchoidal fracture; when, however, it is uniformly crystalline in appearance, yet very close-grained, the name *Anamesite* (from ανάμεσος, intermediate) is employed, but if the rock be so coarsely crystallised that its different mineral constituents can be easily recognised by the eye, it is called *Dolerite* (from δολερος, deceitful), in allusion to the difficulty of distinguishing it from some of the rocks known as plutonic.

The term *Tachylite* is applied to basalt which has assumed the condition of volcanic glass, and is only distinguishable from obsidian by its greater density and softness.

Melaphyre is often quite undistinguishable in external appearance from basalt, of which it may be regarded as simply an altered form. Both these rocks are composed of triclinic felspar and augite with more or less olivine, magnetic or titaniferous oxide of iron, and usually a little apatite. In some cases a part or the whole of the felspar of basalt may be replaced by nepheline, leucite, or häuyn. Basalt usually contains considerably more olivine than melaphyre, but chemically they are closely allied, the olivine in the melaphyres having been altered into various serpentinous products. The term *Melaphyre*, although popular with some writers, is very vague in its signification and therefore of but little scientific value.

Greenstone.—This name has usually been extended to all granular mixtures, whether of hornblende and felspar, or of augite and felspar. *Labrador-rock* is a term used for a compound of labradorite or labrador-felspar and hypersthene; when the hypersthene predominates it is sometimes known under the name of *Hypersthene-rock*, *Hypersthenite*, or *Hyperite*. *Diorite*, *Gabbro*, and *Diabase* are very crystalline rocks, which help to connect the volcanic with the plutonic formations; they will therefore be treated of in Chapter XXXI.

Trachytic Rocks.—The name trachyte (from τραχύς, rough) was originally given to a coarse granular felspathic rock which was rough and gritty to the touch. The term was subsequently made to include other rocks, such as clinkstone and obsidian, which have a similar mineral composition but to which, owing to their different texture, the word in its original meaning would not apply. The felspars which occur in Trachytic rocks are invariably those which contain the largest proportion of silica, or from 60 to 70 per cent. of that mineral. Through the base are usually disseminated crystals of glassy felspar, mica, and

sometimes hornblende. Although quartz is not a necessary ingredient in the composition of this rock, it is very frequently present, and the quartz trachytes are very largely developed in many volcanic districts. In this respect the trachytes differ entirely from the members of the Basaltic family. In chemical composition the quartz-trachytes are allied to the granites, as are also the ordinary trachytes to the syenites.

Obsidian, &c.—Obsidian, Pitchstone, and Pearlstone are only different forms of a volcanic glass produced by the fusion of trachytic rocks. The distinction between them is caused by different rates of cooling from the melted state, as has been proved by experiment. Obsidian is of a black, dark green, or ash-grey colour and vitreous lustre, and though opaque in mass is translucent at the edges. Pitchstone has a resinous lustre, and is more variable in colour than obsidian.

Clinkstone or Phonolite.—Among the rocks closely allied to the trachytes, or those in which the felspars are rich in silica, that termed Clinkstone or Phonolite is conspicuous by its fissile structure, and its tendency to lamination, which is such as sometimes to render it useful as roofing-slate. It rings when struck with the hammer, whence its name; is compact, and usually of a greyish blue or brownish colour, and is composed of that variety of orthoclase felspar called sanidine, together with nepheline and frequently a little hornblende. The name Clinkstone has often been loosely applied to a mere variety of felstone. The only true Phonolite yet recognised in England is that of the Wolf Rock, off the coast of Cornwall.

[An important class of volcanic rocks, now very generally recognised by geologists, is that of the *quartz-trachytes*, *Elyolites* or *Liparites*. They always contain a large proportion of silica, varying from 70 to 80 per cent., and quartz is one of the most abundant of their constituent minerals; moreover, they frequently assume a more or less vitreous aspect. When the trachytic rocks are arranged in a series according to the percentage of silica contained, these rocks form one extreme, while the other extreme of the series is constituted by varieties which link the trachytic with the basaltic groups of rocks and are called *Andesites* from their prevalence in the great volcanic chain of the Andes. These latter rocks consist of materials similar to the ordinary trachytes, but in them some form of plagioclase felspar predominates over the orthoclase. They sometimes contain free quartz and then pass into *quartz-andesites* or *Dacites*, so called from their abundance in Transylvania, the ancient Roman province of Dacia. When forms of trachyte or quartz-trachyte have become 'altered' through chemical changes in

some of their constituent minerals, they are usually distinguished as *felstones.* Through similar changes Andesites have been altered into what are called *Porphyrites,* a term which must not be confounded with 'Porphyry.']

Volcanic rocks distinguished by special forms of structure.—Many volcanic rocks are commonly spoken of under names, denoting structure alone, which must not be taken to imply that they are distinct rocks, *i.e.* that they differ from one another either in mineral or chemical composition. Thus the terms Trachytic porphyry, Trachytic tuff, &c., merely refer to the same rock under different conditions of mechanical aggregation or crystalline development which would be more correctly expressed by the use of the adjective, as porphyritic, trachytic, &c.; but as these terms are so commonly employed it is considered advisable to direct the student's attention to them.

Fig. 592.

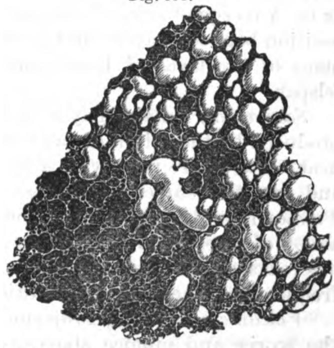
Porphyry.
White crystals of felspar in a dark base of hornblende and felspar.

Porphyry is one of this class, and very characteristic of the volcanic formations. When distinct crystals of one or more minerals are scattered through a compact base, the rock is termed a porphyry (see fig. 592). Thus trachyte is usually porphyritic; for in it, as in many modern lavas, there are crystals of felspar; but in some porphyries the crystals are of augite, olivine, or other minerals. If the base be greenstone, basalt, or pitchstone, the rock is often denominated greenstone-porphyry, pitchstone-porphyry, and so forth. The old classical type of this form of rock is the red porphyry of Egypt, or the well-known 'Rosso antico.' It consists, according to Delesse, of a red felspathic base in which are disseminated rose-coloured crystals of the felspar called oligoclase, with some plates of blackish hornblende and grains of oxide of iron (iron-glance). *Red-quartziferous porphyry* is a much more siliceous rock, containing about 70 or 80 per cent. of silex, while that of Egypt has only 62 per cent.

Amygdaloid.—This is another form of igneous rock admitting of every variety of composition. It comprehends any rock in which round or almond-shaped nodules of some mineral such as agate, chalcedony, calcareous spar, or zeolite are scattered through a base of wacke, basalt, greenstone, or other kind of

trap. It derives its name from the Greek word *amygdalon*, an almond. The origin of this structure cannot be doubted, for we may trace the process of its formation in modern lavas. Small pores or cells are caused by bubbles of steam and gas confined in the melted matter. After or during consolidation, these empty spaces are gradually filled up by matter separating from the mass, or infiltered by water permeating the rock. As these bubbles have been sometimes lengthened by the flow of the lava before it finally cooled, the contents of such cavities have the form of almonds. In some of the amygdaloidal traps of Scotland, where the nodules have decomposed, the empty cells are seen to have a glazed or vitreous coating, and in this respect exactly resemble scoriaceous lavas, or the slags of furnaces.

Fig. 593.



Scoriaceous lava in part converted into an amygdaloid.
Montagne de la Veille, Department of Puy de Dôme, France.

The annexed figure represents a fragment of stone taken from the upper part of a sheet of basaltic lava in Auvergne. One half is scoriaceous, the pores being perfectly empty; the other part is amygdaloidal, the pores or cells being mostly filled up with carbonate of lime, forming white kernels.

Lava.—This term has a somewhat vague signification, having been applied to all melted matter observed to flow in streams from volcanic vents. When this matter consolidates in the open air, the upper part is usually scoriaceous, and the mass becomes more and more stony as we descend, or in proportion as it has consolidated more slowly and under greater pressure. At the bottom, however, of a stream of lava, a small portion of scoriaceous rock very frequently occurs, formed by the first thin sheet of liquid matter, which often precedes the main current, and solidifies under slight pressure.

The more compact lavas are often porphyritic, but even the scoriaceous part sometimes contains imperfect crystals, which have been derived from some older rocks, in which the crystals pre-existed, but were not melted, as being more infusible in their nature. Although melted matter rising in a crater, and even that which enters a rent on the side of a crater, is called lava, yet this term belongs more properly to that which has

flowed either in the open air or on the bed of a lake or sea. There is every variety of composition in lavas; some are trachytic, as in the Peak of Teneriffe; a great number are basaltic, as in Auvergne; others are andesitic, or intermediate in composition between basalts and trachytes, as those of Chili; while many of the lavas of Etna consist of dolerites with labrador-felspar.[5]

Scoriæ and *Pumice* may next be mentioned as porous rocks, produced by the action of gases on materials melted by volcanic heat. *Scoriæ* are usually of a reddish-brown and black colour, and are the cinders and slags of crystalline or stony lavas. *Pumice* is a light, spongy fibrous substance, produced by the action of gases on lavas of glassy structure. Most of the pumiceous rocks are trachytic, and this class of rock occurs much more frequently in the vitreous condition than does the basaltic class.

Volcanic ash or tuff, Trap tuff.—Small angular fragments of the scoriæ and pumice above-mentioned, and the dust of the same, produced by volcanic explosions, form the tuffs which abound in all regions of active volcanos, where showers of these materials, together with small pieces of other rocks ejected from the crater, and more or less burnt, fall down upon the land or into the sea. Here they often become mingled with shells, and are stratified. Such tuffs are sometimes bound together by a calcareous cement, and form a stone susceptible of a beautiful polish. But even when little or no lime is present, there is a great tendency in the materials of ordinary tuffs to cohere together. The term *Volcanic ash* has been much used for rocks of all ages supposed to have been derived from matter ejected in a melted state from volcanic orifices. We meet occasionally with extremely compact beds of volcanic materials, interstratified with fossiliferous rocks. These may sometimes be tuffs, although their density or compactness is such as to cause them to resemble many of those kinds of trap which are found in ordinary dikes.

Wacke is a name given to a decomposed state of various trap rocks of the basaltic family, or those which are poor in silica. It resembles clay of a yellowish or brown colour, and passes gradually from the soft state to the hard dolerite, greenstone or other trap rock from which it has been derived. [Claystone is a similar material produced by the decomposition of andesitic or trachytic lavas.]

Agglomerate.—In the neighbourhood of volcanic vents, we frequently observe accumulations of angular fragments of rocks

[5] G. Rose, Ann. des Mines, tom. viii. p. 32.

formed during eruptions by the explosive action of steam, which shatters the subjacent stony formations and hurls them up into the air. They then fall in showers around the cone or crater, or may be spread for some distance over the surrounding country. The fragments consist usually of different varieties of scoriaceous and compact lavas; but other kinds of rock, such as granite or even fossiliferous limestones, may be intermixed; in short, any substance through which the expansive gases have forced their way. The dispersion of such materials may be aided by the wind, as it varies in direction or intensity, and by the slope of the cone down which they roll, or by floods of rain, which often accompany eruptions. But if the power of running water, or of the waves and currents of the sea, be sufficient to carry the fragments to a distance, it can scarcely fail to wear off their angles, and the formation then becomes a *conglomerate.* If occasionally globular pieces of scoriæ abound in an agglomerate, they may not owe their round form to attrition. Rocks formed by the consolidation of angular fragments of volcanic rocks are usually termed *volcanic breccias.*

Laterite is a red or brick-like rock composed of silicate of alumina and oxide of iron. The red layers, called 'ochre beds,' dividing the lavas of the Giant's Causeway and the Inner Hebrides, which are often called bole or lithomarge, appear to be analogous to the Indian laterites. These were found by Delesse to be trap impregnated with the red oxide of iron, and in part reduced to kaolin. When still more decomposed they were found to be clay coloured by real ochre. As two of the lavas of the Giant's Causeway are parted by a bed of lignite, it is not improbable that the red layers seen in the Antrim cliffs resulted from atmospheric decomposition. In Madeira and the Canary Islands streams of lava of subaërial origin are often divided by red bands of laterite, probably ancient soils formed by the decomposition of the surfaces of lava-currents, many of these soils having been coloured red in the atmosphere by oxide of iron, others burnt into a red brick by the overflowing of heated lavas. These red bands are sometimes prismatic, the small prisms being at right angles to the sheets of lava. Red clay or red marl, formed as above stated by the disintegration of lava, scoriæ, or tuff, has often accumulated to a great thickness in the valleys of Madeira, being washed into them by alluvial action; and some of the thick beds of laterite in India may have had a similar origin. In India, however, especially in the Deccan, the term 'laterite' seems to have been used too vaguely to answer the above definition. The vegetable soil in the gardens of the suburbs of Catania which was overflowed by the lava of

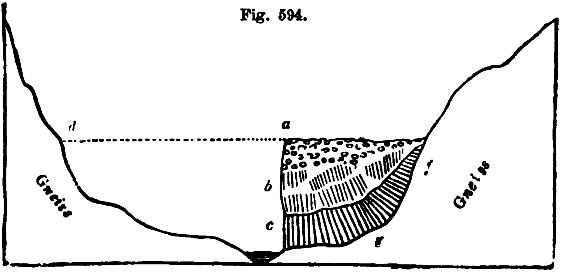
1669 was turned or burnt into a layer of red brick-coloured stone, similar to laterite, which may now be seen supporting the old lava-current.

Columnar and globular structure.—One of the characteristic forms assumed by volcanic rocks is the columnar, a structure often displayed in a very striking manner by basaltic lavas. The columns are sometimes straight, at others curiously curved and twisted; in section they are polygonal, and they are often divided longitudinally by equidistant joints, which sometimes exhibit curved surfaces of articulation; in certain cases the angles of one division of a column are found to project and to form processes which fit into sockets, corresponding to them in the adjoining divisions. Columns of different varieties often occur in the same lava stream, the thick straight articulated columns being found in the lower, and the smaller curved forms in its upper portion; and the line of junction between the two varieties is in many cases very distinctly marked. It is this peculiar combination of columns of different kinds which gives rise to the beautiful and well-known features of the Isle of Staffa; it is equally well seen in many lavas of more recent date.

It being assumed that columnar trap has consolidated from a fluid state, the prisms are said to be always at right angles to the *cooling surfaces*. If these surfaces, therefore, instead of being either perpendicular or horizontal, are curved, the columns ought to be inclined at every angle to the horizon; and there is a beautiful exemplification of this phenomenon in one of the valleys of the Vivarais, a mountainous district in the South of France, where, in the midst of a region of gneiss, a geologist encounters unexpectedly several volcanic cones of loose sand and scoriæ. From the crater of one of these cones, called La Coupe d'Ayzac, a stream of lava has descended and occupied the bottom of a narrow valley, except at those points where the river Volant, or the torrents which join it, have cut away portions of the solid lava. The accompanying sketch (fig. 594) represents the remnant of the lava at one of these points. It is clear that the lava once filled the whole valley up to the dotted line *d a*; but the river has gradually swept away all below that line, while the tributary torrent has laid open a transverse section; by which we perceive, in the first place, that the lava is composed, as usual in this country, of three parts: the uppermost, at *a*, being scoriaceous; the second, *b*, presenting irregular prisms; and the third, *c*, with regular columns, which are vertical on the banks of the Volant, where they rest on a horizontal base of gneiss, but which are inclined at an angle of 45° at *g*, and are nearly horizontal at *f*, their position having been

everywhere determined, according to the law before mentioned, by the form of the original valley.

Fig. 594.

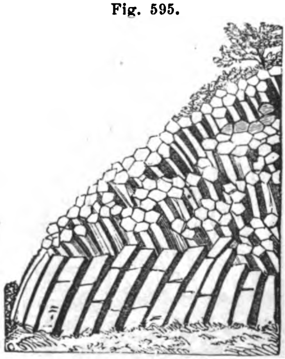


Lava of La Coupe d'Ayzac, near Antraigue, in the Department of Ardèche.

In the annexed figure 595, a view is given of some of the inclined and curved columns which present themselves on the sides of the valleys in the hilly region north of Vicenza, in Italy, and at the foot of the higher Alps.[6] Unlike those of the Vivarais, last mentioned, the basalt of this country was evidently submarine, and the present valleys have since been hollowed out by denudation.

The columnar structure is by no means peculiar to the trap rocks in which augite abounds; it is also observed in trachyte, and other felspathic rocks of the igneous class, although in these it is rarely exhibited in such regular polygonal forms, and never with the ball and socket joints, which form so conspicuous a feature in many basaltic columns. It has been already stated that basaltic columns are often divided by cross joints. Sometimes each segment, instead of an angular, assumes a spheroidal form, usually produced by weathering, so that a pillar is made up of a pile of balls, usually flattened, as in the Cheese-grotto at Bertrich-Baden, in the Eifel, near the Moselle (fig. 596). The basalt there is part of a small stream of lava, from 30 to 40 feet thick, which has proceeded from one of several volcanic craters, still extant, on the neighbouring heights.

Fig. 595.

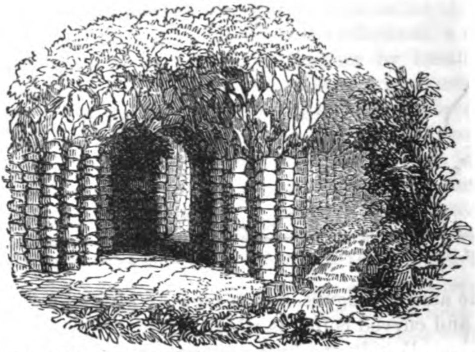


Columnar basalt in the Vicentin. (Fortis.)

[6] Fortis, Mém. sur l'Hist. Nat. de l'Italie, tom. i. p. 233, plate 7.

In some masses of decomposing basalt, greenstone, and other trap rocks, the globular structure is so conspicuous that the rock

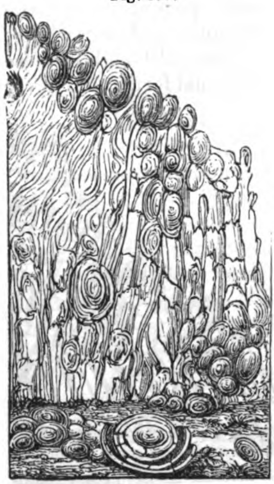
Fig. 596.



Basaltic pillars of the Käsegrotte, Bertrich-Baden, half way between Trèves and Coblentz. Height of grotto, from 7 to 8 feet.

has the appearance of a heap of large cannon-balls. According to M. Delesse, the centre of each spheroid has been a centre of crystallisation, around which the different minerals of the rock arranged themselves symmetrically during the process of cooling. But it was also, he says, a centre of contraction, produced by the same cooling, the globular form, therefore, of such spheroids being the combined result of crystallisation and contraction.[7] To this same contraction we may attribute some cases of columnar structure in sedimentary strata such as volcanic ash, shale, and sandstone, which had been heated by the proximity of volcanic dikes.

Fig. 597.



Globiform pitchstone. Chiaja di Luna, Isle of Ponza. (Scrope.)

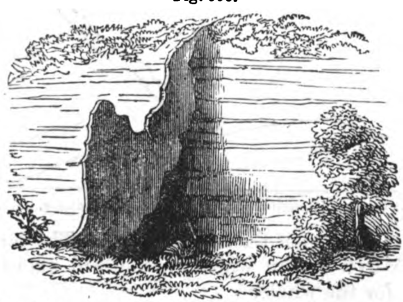
Mr. Scrope gives as an illustration of this structure a resinous trachyte or pitchstone-porphyry in one of the Ponza islands, which rise from the Mediterranean, off the coast of Terracina and Gaeta.

[7] Delesse, Sur les Roches Globuleuses, Mém. de la Soc. Géol. de France, 2 sér. tom. iv.

The globes vary from a few inches to three feet in diameter, and are of an ellipsoidal form (see fig. 597). The whole rock is in a state of decomposition, 'and when the balls,' says Mr. Scrope, 'have been exposed a short time to the weather, they scale off at a touch into numerous concentric coats, like those of a bulbous root, inclosing a compact nucleus. The laminæ of this nucleus have not been so much loosened by decomposition; but the application of a ruder blow will produce a still further exfoliation.'[8] This spheroidal structure may be also seen in volcanic ash at Burntisland and elsewhere.

Volcanic or Trap Dikes.—The leading varieties of the volcanic rocks—basalt, andesite, trachyte, and quartz-trachyte—are found sometimes in dikes penetrating stratified and unstratified formations, sometimes in shapeless masses protruding through or overlying them, or in horizontal sheets intercalated

Fig. 598.



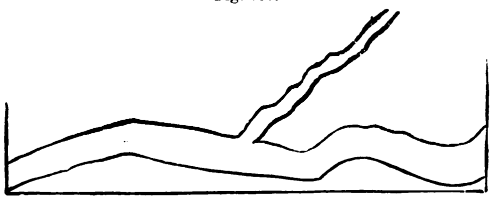
Dike in valley, near Brazen Head, Madeira. (From a drawing of Capt. Basil Hall, R.N.)

between strata. Fissures have already been spoken of as occurring in all kinds of rocks, some a few feet, others many yards in width, and often filled up with earth or angular pieces of stone, or with sand and pebbles. Instead of such materials, suppose a quantity of melted stone to be driven or injected into an open rent, and there consolidated, we have then a tabular mass resembling a wall, and called a dike. It is not uncommon to find such dikes passing through strata of soft materials, such as tuff, scoriæ, or shale, which, being more perishable than the trap, are often washed away by the sea, rivers, or rain, in which case the dike stands prominently out on the face of precipices, or on the level surface of a country, as may be seen in Madeira (see fig. 598) and in many parts of Scotland.

[8] Scrope, Geol. Trans. 2nd series, vol. ii. p. 205.

In the islands of Arran and Skye, and in other parts of Scotland, where sandstone, conglomerate, and other hard rocks are traversed by dikes of trap, the converse of the above phenomenon is also seen. The dike, having decomposed more rapidly than the containing rock, has once more left open the original fissure, often for a distance of many yards inland from the seacoast. There is yet another case, by no means uncommon in Arran and other parts of Scotland, where the strata in contact with the dike, and for a certain distance from it, have been hardened, so as to resist the action of the weather more than the dike itself or the surrounding rocks. When this happens, two parallel walls of indurated strata are seen protruding above the general level of the country and following the course of the dike. In fig. 599, a ground plan is given of a ramifying dike of greenstone, which I observed cutting through sandstone on

Fig. 599.



Ground plan of greenstone dikes traversing sandstone. Arran.

the beach near Kildonan Castle, in Arran. The larger branch varies from 5 to 7 feet in width, which will afford a scale of measurement for the whole.

In the Hebrides and other countries, the same masses of trap which occupy the surface of the country far and wide, concealing the subjacent stratified rocks, are seen also in the sea cliffs, prolonged downwards in veins or dikes, which probably unite with other masses of igneous rock at a greater depth.

Every variety of volcanic rock is sometimes found in dikes, as trachyte, basalt, and all the greenstones, besides the different felstones. The amygdaloidal traps also occur, though rarely, and even tuffs and breccias, for the materials of these last may be washed down into open fissures at the bottom of the sea, or during eruption on the land may be showered into them from the air. Some dikes of trap may be followed for leagues uninterruptedly in nearly a straight direction, as in the North of England, showing that the fissures which they fill must have been of extraordinary length.

Rocks altered by volcanic dikes.—After these remarks on the form and composition of dikes themselves, I shall describe

the alterations which they sometimes produce in the rocks in contact with them. The changes are usually such as the heat of melted matter and of the entangled steam and gases might be expected to cause.

Plas-Newydd: Dike cutting through shale.—A striking example, near Plas-Newydd, in Anglesea, has been described by Professor Henslow.[9] The dike is 134 feet wide, and consists of a rock which is a compound of triclinic felspar and augite. Strata of shale and argillaceous limestone, through which it cuts perpendicularly, are altered to a distance of 30, or even in some places, of 35 feet from the edge of the dike. The shale, as it approaches the trap, becomes gradually more compact, and is most indurated where nearest the junction. Here it loses part of its schistose structure, but the separation into parallel layers is still discernible. In several places the shale is converted into hard porcellanous jasper. In the most hardened part of the mass the fossil shells, principally *Producti*, are nearly obliterated; yet even here their impressions may frequently be traced. The argillaceous limestone undergoes analogous mutations, losing its early texture as it approaches the dike, and becoming granular and crystalline. But the most extraordinary phenomenon is the appearance in the shale of numerous crystals of analcime and garnet, which are distinctly confined to those portions of the rock affected by the dike.[1] Some garnets contain as much as 20 per cent. of lime, which they may have derived from the decomposition of the fossil shells or *Producti*. The same mineral has been observed, under very analogous circumstances, in High Teesdale, by Professor Sedgwick, where it also occurs in shale and limestone, altered by basalt.[2]

Antrim: Dike cutting through chalk.—In several parts of the county of Antrim, in the North of Ireland, chalk with flints is traversed by basaltic dikes. The chalk is there converted into granular marble near the basalt, the change sometimes extending 8 or 10 feet from the wall of the dike, being greatest near the point of contact, and thence gradually decreasing till it becomes evanescent. 'The extreme effect,' says Dr. Berger, 'presents a dark brown crystalline limestone, the crystals running in flakes as large as those of coarse primitive (*metamorphic*) limestone; the next state is saccharine, then fine grained and arenaceous; a compact variety, having a porcellanous aspect and a bluish-grey colour, succeeds: this, towards

[9] Cambridge Transactions, vol. i. p. 402.

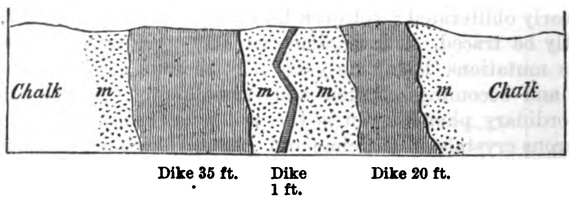
[1] Ibid., vol. i. p. 410.

[2] Cambridge Transactions, vol. ii. p. 175.

the outer edge, becomes yellowish white, and insensibly graduates into the unaltered chalk. The flints in the altered chalk usually assume a grey yellowish colour.'[3] All traces of organic remains are effaced in that part of the limestone which is most crystalline.

The annexed drawing (fig. 600) represents three basaltic dikes traversing the chalk, all within the distance of 90 feet. The chalk contiguous to the two outer dikes is converted into a finely granular marble, *m m*, as are the whole of the masses between the outer dikes and the central one. In some cases the change undergone by the chalk is of a chemical nature, and the rock, besides being indurated and crystallised, is also dolomitised. The entire contrast in the composition and colour of the intrusive and invaded rocks in these cases renders the phenomena peculiarly clear and interesting. Another of the

Fig. 600.



Basaltic dikes in chalk in Island of Rathlin, Antrim.
Ground plan as seen on the beach. (Conybeare and Buckland.[4])

dikes of the North-east of Ireland has converted a mass of red sandstone into hornstone. By another, the shale of the coal-measures has been indurated, assuming the character of flinty slate; and at Portrush the shaly clay of the lias has been changed into flinty slate, which still retains numerous impressions of ammonites.[5]

It might have been anticipated that beds of coal would, from their combustible nature, be affected in an extraordinary degree by the contact of melted rock. Accordingly, one of the greenstone dikes of Antrim, on passing through a bed of coal, reduces it to a cinder for the space of 9 feet on each side. At Cockfield Fell, in the North of England, a similar change is observed. Specimens taken at the distance of about 30 yards from the trap are not distinguishable from ordinary pit-coal; those nearer

[3] Dr. Berger Geol. Trans., 1st ser. vol. iii. p. 172.

[4] Geol. Trans., 1st series, vol. iii. p. 210, and plate 10.

[5] Geol. Trans., 1st series, vol. iii. p. 213; and Playfair, Illust. of Hutt. Theory, s. 253.

the dike are like cinders, and have all the character of coke; while those close to it are converted into a substance resembling soot.[6]

It is by no means uncommon to meet with the same rocks, even in the same districts, almost wholly unchanged in the proximity of volcanic dikes. This great inequality in the effects of the igneous rocks may often arise from an original difference in their temperature, and in that of the entangled gases, such as is ascertained to prevail in different lavas, or in the same lava near its source and at a distance from it. The power also of the invaded rocks to conduct heat may vary, according to their composition, structure, and the fractures which they may have experienced, and perhaps, also, according to the quantity of water (so capable of being heated) which they contain. It must happen in some cases that the component materials are mixed in such proportions as to prepare them readily to enter into chemical union, and form new minerals; while in other cases the mass may be more homogeneous, or the proportions less adapted for such union.

We must also take into consideration, that one fissure may be simply filled with lava, which may begin to cool from the first; whereas in other cases the fissure may give passage to a current of melted matter, which may ascend for days or months, feeding streams which are overflowing the country above, or being ejected in the shape of scoriæ from some crater. If the walls of a rent, moreover, are heated by hot vapour before the lava rises, as we know may happen on the flanks of a volcano, the additional heat supplied by the dike and its gases will act more powerfully.

Intrusion of lava between strata.—Masses of lava are not unfrequently met with intercalated between strata, and maintaining their parallelism to the planes of stratification throughout large areas. They must in some places have forced their way laterally between the divisions of the strata, a direction in which there would be the least resistance to an advancing fluid, if no vertical rents communicated with the surface, and a powerful hydrostatic pressure were caused by gases propelling the lava upwards.

Relation of Trappean rocks to the products of active volcanos.—When we reflect on the changes above described in strata near their contact with trap dikes, and consider how complete is the analogy or often identity in composition and structure of the rocks called Trappean and the lavas of active volcanos, it seems difficult at first to understand how so much doubt could have prevailed for half a century as to whether

6 Sedgwick, Camb. Trans., vol. ii. p. 37.

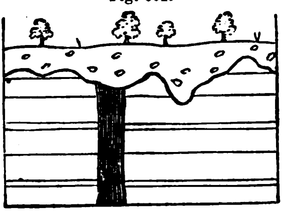
trap was of igneous or aqueous origin. To a certain extent, however, there was a real distinction between the trappean formations and those to which the term volcanic was almost exclusively confined. A large portion of the trappean rocks first studied in the North of Germany, and in Norway, France, Scotland, and other countries, were such as had been formed entirely under water, or had been injected into fissures and intruded between strata, and which had never flowed out in the air, or over the bottom of a shallow sea. When these products, therefore, of submarine or subterranean igneous action were contrasted with loose cones of scoriæ, tuff, and lava, or with narrow streams of lava in great part scoriaceous and porous, such as were observed to have proceeded from Vesuvius and Etna, the resemblance seemed remote and equivocal. It was, in truth, like comparing the roots of a tree with its leaves and branches, which, although they belong to the same plant, differ in form, texture, colour, mode of growth, and position. The external cone, with its loose ashes and porous lava, may be likened to the light foliage and branches, and the rocks concealed far below, to the roots. But it is not enough to say of the volcano,

> quantum vertice in auras
> Ætherias, tantum radice in Tartara tendit,

for its roots do literally reach downwards to Tartarus, or to the regions of subterranean fire; and what is concealed far below is probably always more important in volume and extent than what is visible above ground.

We have already stated how frequently dense masses of strata have been removed by denudation from wide areas (see Chap. VI.); and this fact prepares us to expect a similar destruction of whatever may once have formed the uppermost part of ancient submarine or subaërial volcanos, more especially as those superficial parts are always of the lightest and most perishable materials. The abrupt manner in which dikes of trap usually terminate at the surface (see fig. 601), and the water-worn pebbles of trap in the alluvium which covers the dike, prove incontestably that whatever was uppermost in these formations has been swept away. It is easy, therefore, to conceive that what is gone in regions of trap may have corresponded to what is now visible in active volcanos.

Fig. 601.



Strata intercepted by a trap dike, and covered with alluvium.

As to the absence of porosity in the trappean formations, the appearances are in a great degree deceptive, for all amygdaloids are, as already explained, porous rocks, into the cells of which mineral matter such as silex, carbonate of lime, and other ingredients, have been subsequently introduced (see p. 506); sometimes, perhaps, by secretion during the cooling and consolidation of lavas. In the Little Cumbray, one of the Western Islands, near Arran, the amygdaloid sometimes contains elongated cavities filled with brown spar; and when the nodules have been washed out, the interior of the cavities is glazed with the vitreous varnish so characteristic of the pores of slaggy lavas. Even in some parts of this rock which are excluded from air and water, the cells are empty, and seem to have always remained in this state, and are therefore undistinguishable from some modern lavas.[7]

Dr. MacCulloch, after examining with great attention these and the other igneous rocks of Scotland, observes, 'that it is a mere dispute about terms, to refuse to the ancient eruptions of trap the name of submarine volcanos; for they are such in every essential point, although they no longer eject fire and smoke.' The same author also considers it not improbable that some of the volcanic rocks of the same country may have been poured out in the open air.[8]

It will be seen, in the following chapters, that in the earth's crust there are volcanic tuffs of all ages, containing marine shells, which bear witness to eruptions at many successive geological periods. These tuffs, and the associated trappean rocks, must not be compared to lava and scoriæ which have cooled in the open air. Their counterparts must be sought in the products of modern submarine volcanic eruptions. If it be objected that we have no opportunity of studying these last, it may be answered, that subterranean movements have caused, almost everywhere in regions of active volcanos, great changes in the relative level of land and sea, in times comparatively modern, so as to expose to view the effects of volcanic operations at the bottom of the sea.

[7] Mac-Culloch, West. Islands, vol. ii. p. 487.
[8] Syst. of Geol., vol. ii. p. 114.

CHAPTER XXIX.

ON THE AGES OF VOLCANIC ROCKS.

Tests of relative age of volcanic rocks—Why ancient and modern rocks cannot be identical—Tests by superposition and intrusion—Test by alteration of rocks in contact—Test by organic remains—Test of age by mineral character—Test by included fragments—Post-Tertiary volcanic rocks—Vesuvius, Auvergne, Puy de Côme, and Puy de Pariou—Newer Pliocene volcanic rocks—Cyclopean Isles, Etna, Dikes of Patagonia, Madeira —Older Pliocene volcanic rocks—Italy—Pliocene volcanos of the Eifel —Trass.

Having in the former part of this work referred the sedimentary strata to a long succession of geological periods, we have now to consider how far the volcanic formations can be classed in a similar chronological order. The tests of relative age in this class of rocks are four: 1st, superposition and intrusion, with or without alteration of the rocks in contact; 2nd, organic remains; 3rd, mineral characters; 4th, included fragments of older rocks.

Besides these four tests it may be said in a general way, that volcanic rocks of Primary or Palæozoic antiquity differ from those of the Secondary or Mesozoic age, and these again from the Tertiary and Recent. Not perhaps that they differed originally in a greater degree than the modern volcanic rocks of one region, such as that of the Andes, differ from those of another such as Iceland, but because all rocks permeated by water, especially if its temperature be high, are liable to undergo a slow transmutation, even when they do not assume a new crystalline form like that of the hypogene rocks.

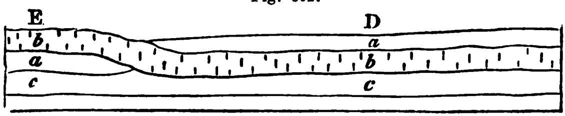
Although subaërial and submarine denudation, as before stated, remove, in the course of ages, large portions of the upper or more superficial products of volcanos, yet these are sometimes preserved by subsidence, becoming covered by the sea or by superimposed marine deposits. In this way they may be protected for ages from the waves of the sea, or the destroying action of rivers, while, at the same time, they may not sink so deep as to be exposed to that plutonic action (to be spoken of in Chapter XXXI.), which would convert them into crystalline rocks. But even in this case, they will not remain unaltered, because they will be percolated by water often of high tempe-

rature and charged with carbonate of lime, silex, iron, and other mineral ingredients, whereby gradual changes in the constitution of the rocks may be superinduced. Every geologist is aware how often silicified trees occur in volcanic tuffs, the perfect preservation of their internal structure showing that they have not decayed before the petrifying material was supplied.

The porous and vesicular nature of a large part, both of the basaltic and trachytic lavas, affords cavities in which silex and carbonate of lime are readily deposited. The minerals of the zeolite family which are so commonly found in amygdaloidal cavities are closely related in composition to the felspars, which, however, differ in being anhydrous. Daubrée and others have shown that the zeolites are formed by the action of percolating water upon the felspathic ingredients of rocks, while Bunsen has also shown in his researches into the volcanic rocks of Iceland that they may be formed directly in molten masses. From these considerations it follows that the perfect identity of appearance and character in very ancient and very modern volcanic formations is scarcely to be expected.

Tests by Superposition.—If a volcanic rock rest upon an aqueous deposit, the volcanic must be the newest of the two; but the like rule does not hold good where the aqueous formation rests upon the volcanic, for melted matter, rising from below, may penetrate a sedimentary mass without reaching the surface, or may be forced in conformably between two strata, as *b* below D in the annexed figure (fig. 602), after which it may

Fig. 602.

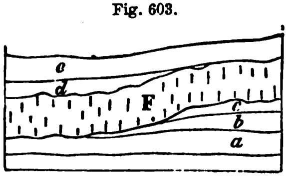


cool down and consolidate. Superposition, therefore, is not of the same value as a test of age in the unstratified volcanic rocks as in fossiliferous formations. We can only rely implicitly on this test where the volcanic rocks are contemporaneous, not where they are intrusive. Now, they are said to be contemporaneous if produced by volcanic action which was going on simultaneously with the deposition of the strata with which they are associated. Thus in the section at D (fig. 602), we may perhaps ascertain that the trap *b* flowed over the fossiliferous bed *c*, and that, after its consolidation, *a* was deposited upon it, *a* and *c* both belonging to the same geological period. But, on the other hand, we must conclude the trap to be intru-

sive, if the stratum *a* be altered by *b* at the point of contact, or if, in pursuing *b* for some distance, we find at length that it cuts through the stratum *a*, and then overlies it as at E.

We may, however, be easily deceived in supposing the volcanic rock to be intrusive, when in reality it is contemporaneous; for a sheet of lava, as it spreads over the bottom of the sea, cannot rest everywhere upon the same stratum, either because these have been denuded, or because, if newly thrown down, they thin out in certain places, thus allowing the lava to cross their edges. Besides, the heavy igneous fluid will often, as it moves along, cut a channel into beds of soft mud and sand. Suppose the submarine lava F (fig. 603) to have come in contact in this manner with the strata *a*, *b*, *c*, and that after its consolidation the strata *d*, *e*, are thrown down in a nearly horizontal position, yet so as to lie unconformably to F, the appearance of subsequent intrusion will here be complete, although the trap is in fact contemporaneous. We must not, therefore, hastily infer that the rock F is intrusive, unless we find the overlying strata *d*, *e*, to have been altered at their junction, as if by heat.

Fig. 603.



The test of age by superposition is strictly applicable to all stratified volcanic tuffs, according to the rules already explained in the case of sedimentary deposits (see p. 100).

Test of age by organic remains.—We have seen how, in the vicinity of active volcanos, scoriæ, pumice, fine sand, and fragments of rock are thrown up into the air, and then showered down upon the land, or into neighbouring lakes or seas. In the tuffs so formed shells, corals, or any other durable organic bodies which may happen to be strewed over the bottom of a lake or sea will be embedded, and thus continue as permanent memorials of the geological period when the volcanic eruption occurred. Tufaceous strata thus formed in the neighbourhood of Vesuvius, Etna, Stromboli, and other volcanos now in islands or near the sea, may give information of the relative age of these tuffs at some remote future period when the fires of these mountains are extinguished. By evidence of this kind we can establish a coincidence in age between volcanic rocks and the different primary, secondary, and tertiary fossiliferous strata.

The tuffs alluded to may not always be marine, but may include, in some places, freshwater shells; in others, the bones

of terrestrial quadrupeds. The diversity of organic remains in formations of this nature is perfectly intelligible, if we reflect on the wide dispersion of ejected matter during late eruptions, such as that of the volcano of Coseguina, in the province of Nicaragua, January 19, 1835. Hot cinders and fine scoriæ were then cast up to a vast height, and covered the ground as they fell to the depth of more than 10 feet for a distance of 8 leagues from the crater in a southerly direction. Birds, cattle, and wild animals were scorched to death in great numbers, and buried in ashes. Some volcanic dust fell at Chiapa, upwards of 1,200 miles, not to leeward of the volcano as might have been anticipated, but to windward, a striking proof of a counter-current in the upper region of the atmosphere; and some on Jamaica, about 700 miles distant to the north-east. In the sea, also, at the distance of 1,100 miles from the point of eruption, Captain Eden of the 'Conway' sailed 40 miles through floating pumice, among which were some pieces of considerable size.[1]

Test of age by mineral composition.—As sediment of homogeneous composition, when discharged from the mouth of a large river, is often deposited simultaneously over a wide space, so a particular kind of lava flowing from a crater during one eruption, may spread over an extensive area; thus in Iceland in 1783, the melted matter, pouring from Skaptar Jokul, flowed in streams in opposite directions, and caused a continuous mass the extreme points of which were 90 miles distant from each other. This enormous current of lava varied in thickness from 100 feet to 600 feet, and in breadth from that of a narrow river gorge to 15 miles.[2] Now, if such a mass should afterwards be divided into separate fragments by denudation, we might still perhaps identify the detached portions by their similarity in mineral composition. Nevertheless, this test will not always avail the geologist; for, although there is usually a prevailing character in lava emitted during the same eruption, and even in the successive currents flowing from the same volcano, still, in many cases, the different parts even of one lava-stream, or, as before stated, of one continuous mass of trap, vary much in mineral composition and texture.

In Auvergne, the Eifel, and other countries where trachyte and basalt are both present, the trachytic rocks are for the most part older than the basaltic. These rocks do, indeed, sometimes alternate partially, as in the volcano of Mount Dore, in Auvergne: and in Madeira trachytic rocks overlie an older

[1] Caldcleugh, Phil. Trans. 1836, p. 27.
[2] See Principles, *Index*, 'Skaptar Jokul.'

basaltic series; but the trachyte occupies more generally an inferior position, and is cut through and overflowed by basalt. It can by no means be inferred that trachyte predominated at one period of the earth's history and basalt at another, for we know that trachytic lavas have been formed at many successive periods, and are still emitted from many active craters; but it seems that in each region, where a long series of eruptions have occurred, the lavas containing felspar more rich in silica have been first emitted, and the escape of the more augitic kinds has followed. The hypothesis suggested by Mr. Scrope may, perhaps, afford a solution of this problem. The minerals, he observes, which abound in basalt are of greater specific gravity than those composing the felspathic lavas; thus, for example, both augite and olivine are more than three times as heavy as water; whereas orthoclase and quartz have a specific gravity of little more than 2·5; and the difference is increased in consequence of there being usually much more iron in state of oxide in basaltic than in trachytic lavas. If, therefore, a large quantity of rock be melted up in the bowels of the earth by volcanic heat, the denser ingredients of the boiling fluid may sink to the bottom, and the lighter remaining above would in that case be first propelled upwards to the surface by the expansive power of gases. Those materials, therefore, which occupy the lowest place in the subterranean reservoir will always be emitted last, and take the uppermost place on the exterior of the earth's crust.

Test by included fragments.—We may sometimes discover the relative age of two trap rocks, or of an aqueous deposit and the trap on which it rests, by finding fragments of one included in the other in cases such as those before alluded to, where the evidence of superposition alone would be insufficient. It is also not uncommon to find a conglomerate almost exclusively composed of rolled pebbles of trap, associated with some fossiliferous stratified formation in the neighbourhood of massive trap. If the pebbles agree generally in mineral character with the latter, we are then enabled to determine its relative age by knowing that of the fossiliferous strata associated with the conglomerate. The origin of such conglomerates is explained by observing the shingle beaches composed of trap pebbles in modern volcanos, as at the base of Etna. I have already alluded (p. 509) to the formation of angular breccias or agglomerates near the mouths of craters.

Post-Tertiary volcanic rocks.—I shall now select examples of contemporaneous volcanic rocks of successive geological periods, to show that igneous causes have been in activity

in all past ages of the world. They have been perpetually shifting the places where they have broken out at the earth's surface, and we can sometimes prove that those areas which are now the great theatres of volcanic action were in a state of perfect tranquillity at remote geological epochs, and that, on the other hand, in places where at former periods the most violent eruptions took place at the surface and continued for a great length of time, there has been an entire suspension of igneous action in historical times, and even, as in the British Isles, throughout a large part of the antecedent Tertiary period. The most recent volcanic rocks in the British Islands are those occurring in the Hebrides and the North of Ireland, which from their intimate association with the Secondary strata were long supposed to be of contemporaneous date with them. But in 1851 the Duke of Argyll and Prof. Edward Forbes proved that a part, at least, of these old lavas were erupted during the Miocene Period. Prof. A. Geikie in 1865 discovered that none of these volcanic rocks are contemporaneous with the Secondary rocks, but that they are all of subsequent, and probably of Tertiary age; while Mr. Judd has recently shown that they are products of three distinct periods of eruption, which with a strong show of probability may be correlated with the Eocene, Miocene, and Pliocene respectively,[3] but the denudation has been such that no perfect cones or craters indicating the exact points of eruption have been preserved. One portion of the lavas, tuffs, and trap-dikes of Etna, Vesuvius, and the island of Ischia has been produced within the historical era; another and a far more considerable part originated at times immediately antecedent, when the waters of the Mediterranean were already inhabited by the existing testacea, but when certain species of elephant, rhinoceros, and other quadrupeds now extinct, inhabited Europe.

Vesuvius.—I have traced in the 'Principles of Geology' the history of the changes which the volcanic region of Campania is known to have undergone during the last 2,000 years. The aggregate effect of igneous operations during that period is far from insignificant, comprising as it does the formation of the modern cone of Vesuvius since the year 79, and the production of several minor cones in Ischia, together with that of Monte Nuovo in the year 1538. Lava-currents have also flowed upon the land and along the bottom of the sea—volcanic sand, pumice, and scoriæ have been showered down so abundantly that whole cities were buried—tracts of the sea have been filled up or con-

[3] Secondary Rocks of Scotland, II., Ancient Volcanos of the Hebrides. Read at the Geol. Soc. of London, Jan. 21, 1874.

verted into shoals—and tufaceous sediment has been transported by rivers and land-floods to the sea. There are also proofs, during the same recent period, of a permanent alteration of the relative levels of the land and sea in several places, and of the same tract having, near Puzzuoli, been alternately upheaved and depressed to the amount of more than 20 feet. In connection with these convulsions, there are found, on the shores of the Bay of Baiæ, recent tufaceous strata, filled with articles fabricated by the hands of man, and mingled with marine shells.

It has also been stated above (p. 186), that when we examine this same region, it is found to consist largely of tufaceous strata, of a date anterior to human history or tradition, which are of such thickness as to constitute hills from 500 to more than 2,000 feet in height. Some of these strata contain marine shells which are exclusively of living species, others contain a slight mixture, 1 or 2 per cent., of species not known as living.

The ancient part of Vesuvius is called Somma, and consists of the remains of an older cone which appears to have been partly destroyed by explosion. In the great escarpment which this remnant of the ancient mountain presents towards the modern cone of Vesuvius, there are many dikes which are for the most part vertical, and traverse the inclined beds of lava and scoriæ which were successively superimposed during those eruptions by which the old cone was formed. They project in relief several inches, or sometimes feet, from the face of the cliff, being extremely compact, and less destructible than the intersected tuffs and porous lavas. In vertical extent they vary from a few yards to 500 feet, and in breadth from 1 to 12 feet. Many of them cut all the inclined beds in the escarpment of Somma from top to bottom, others stop short before they ascend above half-way. In mineral composition they scarcely differ from the lavas of Somma, the rock consisting of a base of leucite and augite, through which large crystals of augite and some of leucite are scattered.

Nothing is more remarkable than the usual parallelism of the opposite sides of the dikes, which correspond almost as regularly as the two opposite faces of a wall of masonry. This character appears at first the more inexplicable, when we consider how jagged and uneven are the rents caused by earthquakes in masses of heterogeneous composition, like those composing the cone of Somma. In explanation of this phenomenon, M. Necker refers us to Sir W. Hamilton's account of an eruption of Vesuvius in the year 1779, who records the following fact :—'The lavas, when they either boiled over the crater, or broke out from the conical parts of the volcano, constantly formed channels

as regular as if they had been cut by art down the steep part of the mountain; and whilst in a state of perfect fusion, continued their course in those channels, which were sometimes full to the brim, and at other times more or less so, according to the quantity of matter in motion.

'These channels' (says the same observer), 'I have found upon examination after an eruption, to be in general from two to five or six feet wide, and seven or eight feet deep. They were often hid from the sight by a quantity of scoriæ that had formed a crust over them; and the lava, having been conveyed in a covered way for some yards, came out fresh again into an open channel. After an eruption, I have walked in some of those subterraneous or covered galleries, which were exceedingly curious, the sides, top, and bottom *being worn perfectly smooth and even* in most parts, by the violence of the currents of the red-hot lavas which they had conveyed for many weeks successively.' I was able to verify this phenomenon in 1858, when a stream of lava issued from a lateral cone.[4] Now, the walls of a vertical fissure, through which lava has ascended in its way to a volcanic vent, must have been exposed to the same erosion as the sides of the channels before adverted to. The prolonged and uniform friction of the heavy fluid, as it is forced and made to flow upwards, cannot fail to wear and smooth down the surfaces on which it rubs, and the intense heat must melt all such masses as project and obstruct the passage of the incandescent fluid.

The rock composing the dikes both in the modern and ancient part of Vesuvius is far more compact than that of ordinary lava, for the pressure of a column of melted matter in a fissure greatly exceeds that in an ordinary stream of lava; and pressure checks the expansion of those gases which give rise to vesicles in lava. There is a tendency in almost all the Vesuvian dikes to divide into horizontal prisms, a phenomenon in accordance with the formation of vertical columns in horizontal beds of lava; for in both cases the divisions which give rise to the prismatic structure are at right angles to the cooling surfaces. (See above, p. 510.)

Auvergne.—Although the latest eruptions in Central France seem to have long preceded the historical era, they are so modern as to have a very intimate connection with the present superficial outline of the country and with the existing valleys and river-courses. Among a great number of cones with perfect craters, one called the Puy de Tartaret sent forth a lava-cur-

[4] Principles of Geology, vol. i. p. 626.

rent which can be traced up to its crater and which flowed for a distance of 13 miles along the bottom of the present valley to the village of Nechers, covering the alluvium of the old valley in which were preserved the bones of an extinct species of horse, and of a lagomys and other quadrupeds all closely allied to recent animals, while the associated land-shells were of species now living, such as *Cyclostoma elegans*, *Helix hortensis*, *H. nemoralis*, *H. lapicida*, and *Clausilia rugosa*. That the current which has issued from the Puy de Tartaret may, nevertheless, be very ancient in reference to the events of human history, we may conclude, not only from the divergence of the mammiferous fauna from that of our day, but from the fact that a Roman bridge of such form and construction as continued in use only down to the fifth century, but which may be older, is now seen at a place about a mile and a half from St. Nectaire. This ancient bridge spans the river Couze with two arches, each about 14 feet wide. These arches spring from the lava of Tartaret, on both banks, showing that a ravine precisely like that now existing had already been excavated by the river through that lava thirteen or fourteen centuries ago.

While the river Couze has in most cases, as at the site of this ancient bridge, been simply able to cut a deep channel through the lava the lower portion of which is shown to be columnar, the same torrent has in other places, where the valley was contracted to a narrow gorge, had power to remove the entire mass of basaltic rock, causing for a short space a complete breach of continuity in the volcanic current. The work of erosion has been very slow, as the basalt is tough and hard, and one column after another must have been undermined and reduced to pebbles, and then to sand. During the time required for this operation, the perishable cone of Tartaret, occupying the lowest part of the great valley descending from Mount Dore and damming up the river so as to cause the Lake of Chambon, has stood uninjured, proving that no great flood or deluge can have passed over this region in the interval between the eruption of Tartaret and our own times.

Puy de Côme.—The Puy de Côme and its lava-current, near Clermont, may be mentioned as another minor volcano of about the same age. This conical hill rises from the granitic platform, at an angle of between 30° and 40°, to the height of more than 900 feet. Its summit presents two distinct craters, one of them with a vertical depth of 250 feet. A stream of lava takes its rise at the western base of the hill instead of issuing from either crater, and descends the granitic slope towards the present site of the town of Pont Gibaud. Thence it pours in a

broad sheet down a steep declivity into the valley of the Sioule, filling the ancient river-channel for the distance of more than a mile. The Sioule, thus dispossessed of its bed, has worked out a fresh one between the lava and the granite of its western bank; and the excavation has disclosed, in one spot, a wall of columnar basalt about 50 feet high.[5]

The excavation of the ravine is still in progress, every winter some columns of basalt being undermined and carried down the channel of the river, and in the course of a few miles rolled to sand and pebbles. Meanwhile the cone of Côme remains unimpaired, its loose materials being protected by a dense vegetation, and the hill standing on a ridge not commanded by any higher ground, so that no floods of rain-water can descend upon it. There is practically no end to the waste which the hard basalt may undergo in future, if the physical geography of the country continue unchanged, no limit to the number of years during which the heap of incoherent and transportable materials called the Puy de Côme may remain in an almost stationary condition.

Puy de Pariou.—The brim of the crater of the Puy de Pariou, near Clermont, is so sharp, and has been so little blunted by time, that it scarcely affords room to stand upon. This and other cones in an equally remarkable state of integrity have stood, I conceive, uninjured, not *in spite* of their loose porous nature, as might at first be naturally supposed, but in consequence of it. No rills can collect where all the rain is instantly absorbed by the sand and scoriæ, as is remarkably the case on Etna; and nothing but a waterspout breaking directly upon the Puy de Pariou could carry away a portion of the hill, so long as it is not rent or engulphed by earthquakes.[6]

Newer Pliocene volcanic rocks.—The more ancient portion of Vesuvius and Etna originated at the close of the Newer Pliocene period, when less than ten, sometimes only one, in a hundred of the shells differed from those now living. In the case of Etna, it was before stated (p. 186) that Pleistocene formations occur in the neighbourhood of Catania, while the oldest lavas of the great volcano are Pliocene. These last are seen associated with sedimentary deposits at Trezza and other places on the southern and eastern flanks of the great cone.

Cyclopean Islands.—The Cyclopean Islands, called by the Sicilians Dei Faraglioni, in the sea-cliffs of which these beds of clay,

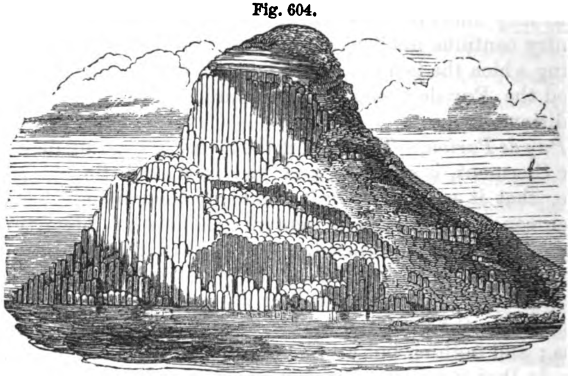
[5] Scrope's Central France, p. 60, and plate.

[6] I have elsewhere shown (Antiquity of Man, 4th ed., 1873, p. 288) that in the neighbouring district of the Velay or Haute Loire, about 50 miles S.E. of Clermont, there are proofs of the eruptions having reached down to the human, though not to the historical period.

lava, and tuff are laid open to view, are situated in the Bay of Trezza, and may be regarded as the extremity of a promontory severed from the mainland. Here numerous proofs are seen of submarine eruptions, by which the argillaceous and sandy strata were invaded and cut through, and tufaceous breccias formed. Enclosed in these breccias are many angular and hardened fragments of laminated clay in different states of alteration by heat, and intermixed with volcanic sands.

The loftiest of the Cyclopean islets, or rather rocks, is about 200 feet in height, the summit being formed of a mass of stratified clay, the laminæ of which are occasionally subdivided by thin arenaceous layers. These strata dip to the N.W., and rest on a mass of columnar lava (see fig. 604) in which the tops

Fig. 604.



View of the Isle of Cyclops in the Bay of Trezza.
(Drawn by Capt. Basil Hall, R.N.)

of the pillars are weathered, and so rounded as to be often hemispherical. In some places in the adjoining and largest islet of the group, which lies to the north-eastward of that represented in the drawing (fig. 604), the overlying clay has been greatly altered and hardened by the igneous rock, and occasionally contorted in the most extraordinary manner; yet the lamination has not been obliterated, but, on the contrary, rendered much more conspicuous, by the indurating process.

In the woodcut (fig. 605), I have represented a portion of the altered rock, a few feet square, where the alternating thin laminæ of sand and clay are contorted in a manner often observed in ancient metamorphic schists. A great fissure, running from east to west, nearly divides this larger island into two parts, and lays open its internal structure. In the section

thus exhibited, a dike of lava is seen, first cutting through an older mass of lava, and then penetrating the superincumbent tertiary strata. In one place the lava ramifies and terminates in thin veins, from a few feet to a few inches in thickness (see fig. 606). The arenaceous laminæ are much hardened at the

Fig. 605.

Contortions of strata in the largest of the Cyclopean Islands.

Fig. 606.

b a b c a b

Newer pliocene strata invaded by lava, Isle of Cyclops (horizontal section).

a. Lava. *b*. Laminated clay and sand. *c*. The same altered.

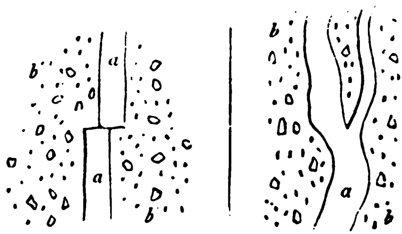
point of contact, and the clays are converted into siliceous schist. In this island the altered rocks assume a honeycomb structure on their weathered surface, singularly contrasted with the smooth and even outline which the same beds present in their usual soft and yielding state.

Dikes of Palagonia.—Dikes of vesicular and amygdaloidal lava are also seen traversing marine tuff or peperino, west of Palagonia, some of the pores of the lava being empty, while others are filled with carbonate of lime. In such cases we may suppose the tuff to have resulted from showers of volcanic sand and scoriæ, together with fragments of limestone, thrown out by a submarine explosion similar to that which gave rise to Graham Island in 1831. When the mass was, to a certain degree, consolidated, it may have been rent open, so that the lava ascended through fissures, the walls of which were perfectly even and parallel. In one case after the melted matter that filled the rent (fig. 607) had cooled down, it must have been fractured and shifted horizontally by a lateral movement.

In the second figure (fig. 608), the lava has more the appearance of a vein, which forced its way through the peperino. It

is highly probable that similar appearances would be seen, if we could examine the floor of the sea in that part of the Mediter-

Fig. 607. Fig. 608.



Ground-plan of dikes near Palagonia.

a. Lava. *b.* Peperino, consisting of volcanic sand, mixed with fragments of lava and limestone.

ranean where the waves have recently washed away the new volcanic island; for when a superincumbent mass of ejected fragments has been removed by denudation, we may expect to see sections of dikes traversing tuff, or, in other words, sections of the channels of communication by which the subterranean lavas reached the surface.

Madeira.—Although the more ancient portion of the volcanic eruptions by which the island of Madeira and the neighbouring one of Porto Santo were built up, occurred, as we shall presently see, in the Upper Miocene period, a still larger part of the island is of Pliocene date. That the latest outbreaks belonged to the Newer Pliocene period, I infer from the close affinity to the present flora of Madeira of the fossil plants preserved in a leaf-bed in the north-eastern part of the island. These fossils, associated with some lignite in the ravine of the river San Jorge, can none of them be proved to be of extinct species, but their antiquity may be inferred from the following considerations. Firstly—The leaf-bed, discovered by Mr. Hartung and myself in 1853, at the height of 1,000 feet above the level of the sea, crops out at the base of a cliff formed by the erosion of a gorge, cut through alternating layers of basalt and scoriæ, the product of a vast succession of eruptions of unknown date, piled up to a thickness of 1,000 feet, and which were all poured out after the plants, of which about 20 species have been recognised, flourished in Madeira. These lavas are inclined at an angle of about 15° to the north, and came down from the great central region of eruption. Their accumulation implies a long period of intermittent volcanic action, subsequently to which the ravine of San Jorge was hollowed out. Secondly—Some

few of the plants, though perhaps all of living genera, are supposed to be of species not now existing in the island. They have been described by Sir Charles Bunbury and Professor Heer, and the former first pointed out that many of the leaves are of the laurel type and analogous to those now flourishing in the modern forests of Madeira. He also recognised among them the leaves of *Woodwardia radicans*, and *Davallia Canariensis*, ferns now abundant in Madeira. Thirdly—The great age of this leaf-bed of San Jorge, which was perhaps originally formed in the crater of some ancient volcanic cone afterwards buried under lava, is proved by its belonging to a part of the eastern extremity of Madeira, which, after the close of the igneous eruptions, became covered in the adjoining district of Caniçal with blown sand in which a vast number of land shells were buried. These fossil shells belonged to no less than 36 species, among which are many now extremely rare in the island, and others, about 5 per cent., extinct or unknown in any part of the world. Several of these of the genus *Helix* are conspicuous from the peculiarity of their forms, others from their large dimensions. The geographical configuration of the country shows that this shell-bed is considerably more modern than the leaf-bed; it must therefore be referred to the Newer Pliocene according to the definition of this period given in a former chapter (p. 120).

Older Pliocene Period.—*Italy.*—In Tuscany, as at Radicofani, Viterbo, and Aquapendente, and in the Campagna di Roma, submarine volcanic tuffs are interstratified with the Older Pliocene strata of the Subapennine hills in such a manner as to leave no doubt that they were the products of eruptions which occurred when the shelly marls and sands of the Subapennine hills were in the course of deposition. This opinion I expressed [7] after my visit to Italy in 1828, and it was confirmed in 1850 by the arguments adduced by Sir R. Murchison in favour of the submarine origin of the Tertiary volcanic rocks of Italy.[8] These rocks are well known to rest conformably on the Subapennine marls, even as far south as Monte Mario in the suburbs of Rome. On the exact age of the deposits of Monte Mario new light has recently been thrown by a careful study of their marine fossil shells, undertaken by MM. Rayneval, Vanden Hecke, and Ponzi. They have compared no less than 160 species with the shells of the Coralline Crag of Suffolk, so well described by Mr. Searles Wood; and the specific agreement

[7] See 1st edit. of Principles of Geology, vol. iii. chaps. xiii. and xiv. 1833; and former edits. of this work, chap. xxxi.

[8] Quart. Geol. Journ., vol. vi. p. 281.

between the British and Italian fossils is so great, if we make due allowance for geographical distance and the difference of latitude, that we can have little hesitation in referring both to the same period, or to the Older Pliocene of this work. It is highly probable that, between the oldest trachytes of Tuscany and the newest rocks in the neighbourhood of Naples, a series of volcanic products might be detected of every age from the Older Pliocene to the historical epoch.

Pliocene Volcanos of the Eifel.—Some of the most perfect cones and craters in Europe, not even excepting those of the district round Vesuvius, may be seen on the left or west bank of the Rhine, near Bonn and Andernach. They exhibit characters distinct from any which I have observed elsewhere, owing to the large part which the escape of aqueous vapour has played in the eruptions and the small quantities of lava emitted. The fundamental rocks of the district are grey and red sandstones and shales, with some associated limestones, replete with fossils of the Devonian or Old Red Sandstone group. The volcanos broke out in the midst of these inclined strata, and when the present systems of hills and valleys had already been formed. The eruptions occurred sometimes at the bottom of deep valleys, sometimes on the summit of hills, and frequently on intervening platforms. In travelling through this district we often come upon them most unexpectedly, and may find ourselves on the very edge of a crater before we had been led to suspect that we were approaching the site of any igneous outburst. Thus, for example, on arriving at the village of Gemund, immediately south of Daun, we leave the stream, which flows at the bottom of a deep valley in which strata of sandstone and shale crop out. We then climb a steep hill, on the surface of which we see the edges of the same strata dipping inwards towards the mountain. When we have ascended to a considerable height, we see fragments of scoriæ sparingly scattered over the surface; until, at length, on reaching the summit, we find ourselves suddenly on the edge of a *tarn*, or deep circular lake-basin called the Gemunder Maar. In it we recognise the ordinary form of a crater, for which we have been prepared by the occurrence of scoriæ scattered over the surface of the soil. But on examining the walls of the crater we find precipices of sandstone and shale which exhibit no signs of the action of heat; and we look in vain for those beds of lava and scoriæ, dipping outwards on every side, which we have been accustomed to consider as characteristic of volcanic vents. As we proceed, however, to the opposite side of the lake, we find a considerable quantity of scoriæ and some

lava, and see the whole surface of the soil sparkling with volcanic sand, and strewed with ejected fragments of half-fused shale, which preserves its laminated texture in the interior, while it has a vitrified or scoriform coating.

Other crater-lakes of circular or oval form, and hollowed out of similar ancient strata, occur in the Upper Eifel, where copious aëriform discharges have taken place, throwing out vast heaps of pulverised shale into the air. I know of no other extinct volcanos where gaseous explosions of such magnitude have been attended by the emission of so small a quantity of lava. Yet I looked in vain in the Eifel for any appearances which could lend support to the hypothesis that the sudden rushing out of such enormous volumes of gas had ever lifted up the stratified rocks immediately around the vent, so as to form conical masses, having their strata dipping outwards on all sides from a central axis, as is assumed in the theory of elevation craters, alluded to in the last chapter.

I have already given (p. 512, fig. 596) an example in the Eifel of a small stream of lava which issued from one of the craters of that district at Bertrich-Baden. It shows that when some of these volcanos were in action the valleys had already been eroded to their present depth.

Trass.—The tufaceous alluvium called *trass*, which has covered large areas in the Eifel, and choked up some valleys now partially re-excavated, is unstratified. Its base consists almost entirely of pumice, in which are included fragments of basalt, and other lavas, pieces of burnt shale, slate, and sandstone, and numerous trunks and branches of trees. If, as is probable, this trass was formed during the period of volcanic eruptions, it may have originated in the manner of the moya of the Andes.

We may easily conceive that a similar mass might now be produced, if a copious evolution of gases should occur in one of the lake-basins. If a breach should be made in the side of the cone, the flood would sweep away great heaps of ejected fragments of shale and sandstone, which would be borne down into the adjoining valleys. Forests might be torn up by such a flood, and thus the occurrence of the numerous trunks of trees dispersed irregularly through the trass can be explained. The manner in which this trass conforms to the shape of the present valleys implies its comparatively modern origin, probably one dating no further back than the Pliocene period.

CHAPTER XXX.

AGE OF VOLCANIC ROCKS—*continued.*

Volcanic rocks of the Upper Miocene Period—Madeira—Grand Canary—Azores—Lower Miocene Volcanic rocks—Isle of Mull—Staffa and Antrim—The Eifel—Upper and Lower Miocene Volcanic rocks of Auvergne—Hill of Gergovia—Eocene Volcanic rocks of the Hebrides—Of Monte Bolca—Trap of Cretaceous period—Oolitic Period—Triassic Period—Permian Period—Carboniferous Period—Erect trees buried in Volcanic Ash in the Island of Arran—Old Red Sandstone Period—Silurian Period—Cambrian Period—Laurentian Volcanic rocks.

Volcanic rocks of the Upper Miocene Period.—*Madeira.*—The greater part of the volcanic eruptions of Madeira, as we have already seen, p. 532, belong to the Pliocene period, but the most ancient of them are of Upper Miocene date, as shown by the fossil shells included in the marine tuffs which have been upraised at San Vicente in the northern part of the island to the height of 1,300 feet above the level of the sea. A similar marine and volcanic formation constitutes the fundamental portion of the neighbouring island of Porto Santo, forty miles distant from Madeira, and is there elevated to an equal height, and covered, as in Madeira, with lavas of sub-aërial origin.

The largest number of fossils have been collected from the tuffs and conglomerates and some beds of limestone in the island of Baixo, off the southern extremity of Porto Santo. They amount in this single locality to more than sixty in number, of which about fifty are mollusca, but many of these are only casts. Some of the shells probably lived on the spot during the intervals between eruptions, and some may have been cast up into the water or air together with muddy ejections, and, falling down again, have been deposited on the bottom of the sea. The hollows in some of the fragments of vesicular lava, of which the breccias and conglomerates are composed, are partially filled with calc-sinter, being thus half converted into amygdaloids. Among the fossil shells common to Madeira and Porto Santo, large cones, strombs, and cowries are conspicuous among the univalves, and *Cardium*, *Spondylus*, and *Lithodomus* among the lamellibranchiate bivalves, and among the *Echinoderms* the large Clypeaster called *C. altus*, an extinct European Miocene fossil.

The largest list of fossils has been published by Mr. Karl Mayer, in Hartung's 'Madeira;' but in the collection made by myself, and in a still larger one formed by Mr. J. Yate Johnson, several remarkable forms not in Mayer's list occur, as, for example, *Pholadomya*, and a large *Terebra*. Mr. Johnson also found a fine specimen of *Nautilus* (*Aturia*) *ziczac* (fig. 210, p. 248), a well-known Falunian and Eocene fossil of Europe; and in the same volcanic tuff of Baixo, the Echinoderm *Brissus Scillæ*, a living Mediterranean species, found fossil in the Miocene strata of Malta. Mr. Mayer identifies one-third of the Madeira shells with known European Miocene (or Falunian) forms. The huge Strombus of San Vicente and Porto Santo, *S. Italicus*, is an extinct shell of the Subapennine or Older Pliocene formations. The mollusca already obtained from various localities of Madeira and Porto Santo are not less than one hundred in number, and, according to the late Dr. S. P. Woodward, rather more than a third are of species still living, but many of these are not now inhabitants of the neighbouring sea.

It has been remarked (p. 194) that in the Older Pliocene and Upper Miocene deposits of Europe, many forms occur of a more southern aspect than those now inhabiting the nearest sea. In like manner the fossil corals, or Zoantharia, six in number, which I obtained from Madeira, of the genera *Astræa*, *Sarcinula*, *Hydnophora*, were pronounced by Mr. Lonsdale to be forms foreign to the adjacent coasts, and agreeing with the fauna of a sea warmer than that now separating Madeira from the nearest part of the African coast. We learn, indeed, from the observations made in 1859, by the Rev. R. T. Lowe, that more than one-half, or fifty-three in ninety, of the marine mollusca collected by him from the sandy beach of Mogador are common British species, although Mogador is 18½ degrees south of the nearest shores of England. The living shells of Madeira and Porto Santo are in like manner those of a temperate climate, although in great part differing specifically from those of Mogador.[1]

Grand Canary.—In the Canaries,[2] especially in the Grand Canary, the same marine Upper Miocene formation is found. Stratified tuffs, with intercalated conglomerates and lavas, are there seen in nearly horizontal layers in sea-cliffs about 300 feet high, near Las Palmas. Mr. Hartung and I were unable to find marine shells in these tuffs at a greater elevation than 400 feet

[1] Linnean Proceedings; Zoology, 1860.

[2] For a complete description of the volcanic island of Palma, one of the Canary Islands, see Elements of Geology, 1865, p. 621.

above the sea ; but as the deposit to which they belong reaches to the height of 1,100 feet or more in the interior, we conceive that an upheaval of at least that amount has taken place. The *Clypeaster altus*, *Spondylus gæderopus*, *Pectunculus pilosus*, *Cardita calyculata*, and several other shells, serve to identify this formation with that of the Madeiras, and *Ancillaria glandiformis*, which is not rare, and some other fossils, remind us of the faluns of Touraine.

The sixty-two Miocene species which I collected in the Grand Canary were referred, by the late Dr. S. P. Woodward, to forty-seven genera, ten of which are no longer represented in the neighbouring sea, namely *Corbis*, an African form, *Hinnites*, now living in Oregon, *Thecidium* (*T. Mediterraneum*, identical with the Miocene fossil of St. Juvat, in Brittany), *Calyptræa*, *Hipponyx*, *Nerita*, *Erato*, *Oliva*, *Ancillaria*, and *Fasciolaria*.

These tuffs of the southern shores of the Grand Canary, containing the Upper Miocene shells, appear to be about the same age as the most ancient volcanic rocks of the island. Over the marine lavas and tuffs trachytic and basaltic products of subaërial volcanic origin, between 4,000 and 5,000 feet in thickness, have been piled, the central parts of the Grand Canary reaching the height of about 6,000 feet above the level of the sea. A large portion of this mass is of Pliocene date, and some of the latest lavas have been poured out since the time when the valleys were already excavated to within a few feet of their present depth.

On the whole the rocks of the Grand Canary, an island of a nearly circular shape, and 6½ geographical miles diameter, exhibit proofs of a long series of eruptions beginning like those of Madeira, Porto Santo, and the Azores, in the Upper Miocene period, and continued to the Pleistocene Period. The building up of the Grand Canary by subaërial eruptions, several thousand feet thick, went on simultaneously with the gradual upheaval of the earliest products of submarine eruptions, in the same manner as the Pliocene marine strata of the oldest parts of Vesuvius and Etna have been upraised during eruptions of Post-tertiary date.

In proof that movements of elevation have actually continued down to Post-tertiary times, I may remark that I found raised beaches containing shells of the Recent Period in the Grand Canary, Teneriffe, and Porto Santo. The most remarkable raised beach which I observed in the Grand Canary, in the study of which I was assisted by Don Pedro Maffiotte, is situated in the north-eastern part of the island at San Catalina, about a quarter of a mile north of Las Palmas. It intervenes

between the base of the high cliff formed of the tuffs with Miocene shells and the sea shore. From this beach, at an elevation of twenty-five feet above high-water mark, and at a distance of about 150 feet from the present shore, I obtained more than fifty species of living marine shells. Many of them, according to Dr. S. P. Woodward, are no longer inhabitants of the contiguous sea, as, for example, *Strombus bubonius*, which is still living on the West Coast of Africa, *Cerithium procerum*, found at Mozambique; others are Mediterranean species, as *Pecten Jacobæus* and *P. polymorphus*. Some of these testacea, such as *Cardita squamosa*, are inhabitants of deep water, and the deposit on the whole seems to indicate a depth of water exceeding a hundred feet.

Azores.—In the island of St. Mary's, one of the Azores, marine fossil shells have long been known. They are found on the north-east coast on a small projecting promontory called Ponta do Papagaio (or Point Parrot), chiefly in a limestone about 20 feet thick, which rests upon, and is again covered by, basaltic lavas, scoriæ, and conglomerates. The pebbles in the conglomerate are cemented together with carbonate of lime.

Mr. Hartung, in his account of the Azores, published in 1860, describes twenty-three shells from St. Mary's,[3] of which eight perhaps are identical with living species, and twelve are with more or less certainty referred to European Tertiary forms, chiefly Upper Miocene. One of the most characteristic and abundant of the new species, *Cardium Hartungi*, not known as fossil in Europe, is very common in Porto Santo and Baixo, and serves to connect the Miocene fauna of the Azores and the Madeiras. In some of the Azores, as well as in the Canary Islands, the volcanic fires are not yet extinct, as the recorded eruptions of Lanzeróte, Teneriffe, Palma, St. Michael's, and others attest. The late soundings (1873) of H.M.S. *Challenger* have shown the Azores, Canaries, Cape de Verde Islands, &c., to be merely the highest summits of a great submerged mountain ridge, comparable with the Andes of South America both in extent and altitude, as well as in the volcanic character of many of its most elevated peaks.

Lower Miocene volcanic rocks.—*Isle of Mull and Antrim.*—I may refer the reader to the account already given (p. 230) of leaf-beds at Ardtun, in the Isle of Mull in the Hebrides, which bear a relation to the associated volcanic rocks of Lower Miocene date analogous to that which the Madeira leaf-bed, above described (p. 532), bears to the Pliocene lavas of that

[3] Hartung, Die Azoren, 1860; also Insel Gran Canaria, Madeira and Porto Santo, 1864, Leipsig.

island. At Ballypalidy and Shane's Castle in the County of Antrim, similar plants of Miocene species have been found in beds intercalated with the basalts; and both in Antrim and Mull the basalts are seen to lie unconformably upon the highest strata of the Chalk. The Miocene basaltic lavas constitute great plateaux, which must originally have covered many thousands of square miles, though now broken up by denudation into a number of disconnected fragments; the lavas are often piled upon one another to a thickness of more than 2,000 feet.[4] The interesting features displayed by these basalts at the Giant's Causeway in Antrim and at Fingal's Cave in the Isle of Staffa are too well known to require description.

The Eifel.—A large portion of the volcanic rocks of the Lower Rhine and the Eifel are coeval with the Lower Miocene deposits to which most of the 'Brown-Coal' of Germany belongs. The Tertiary strata of that age are seen on both sides of the Rhine, in the neighbourhood of Bonn, resting unconformably on highly inclined and vertical strata of Silurian and Devonian rocks. The Brown-Coal formation of that region consists of beds of loose sand, sandstone, and conglomerate, clay with nodules of clay-ironstone, and occasionally silex. Layers of light brown, and sometimes black lignite are interstratified with the clays and sands, and often irregularly diffused through them. They contain numerous impressions of leaves and stems of trees, and are extensively worked for fuel, whence the name of the formation. In several places, layers of trachytic tuff are interstratified, and in these tuffs are leaves of plants identical with those found in the brown-coal, showing that, during the period of the accumulation of the latter, some volcanic products were ejected. The igneous rocks of the Westerwald, and of the mountains called the Siebengebirge, consist partly of basaltic and partly of trachytic lavas, the latter being in general the more ancient of the two. There are many varieties of trachyte, some of which are highly crystalline, resembling a coarse-grained granite, with large separate crystals of felspar. Trachytic tuff is also very abundant.

M. Von Dechen, in his work on the Siebengebirge,[5] has given a copious list of the animal and vegetable remains of the fresh-water strata associated with the brown-coal of that part of Germany. Plants of the genera *Flabellaria*, *Ceanothus*, and *Daphnogene*, including *D. cinnamomifolia* (fig. 158, p. 221), occur in these beds, with nearly 150 other plants. The fishes of the brown-coal near Bonn are found in a bituminous shale,

[4] Judd, 'Ancient Volcanos of the Highlands,' Geol. Soc., Jan. 21, 1874.

[5] Geognost. Beschreib. des Siebengebirges am Rhein. Bonn, 1852.

called paper-coal, from being divisible into extremely thin leaves. The individuals are very numerous; but they appear to belong to a small number of species, some of which were referred by Agassiz to the genera *Leuciscus*, *Aspius*, and *Perca*. The remains of frogs also, of extinct species, have been discovered in the paper-coal; and a complete series may be seen in the Museum at Bonn, from the most imperfect state of the tadpole to that of the full-grown animal. With these a salamander, scarcely distinguishable from the recent species, has been found, and the remains of many insects.

Upper and Lower Miocene volcanic rocks of Auvergne. —The extinct volcanos of Auvergne and Cantal in Central France, seem to have commenced their eruptions in the Lower Miocene period, but to have been most active during the Upper Miocene and Pliocene eras. I have already alluded to the grand succession of events, of which there is evidence in Auvergne since the last retreat of the sea (see p. 527).

The earliest monuments of the Tertiary period in that region are lacustrine deposits of great thickness, in the lowest conglomerates of which are rounded pebbles of quartz, mica-schist, granite, and other non-volcanic rocks, without the slightest intermixture of igneous products. To these conglomerates succeed argillaceous and calcareous marls and limestones, containing Lower Miocene shells and bones of mammalia, the higher beds of which sometimes alternate with volcanic tuff of contemporaneous origin. After the filling up or drainage of the ancient lakes, huge piles of trachytic and basaltic rocks, with volcanic breccias, accumulated to a thickness of several thousand feet, and were superimposed upon granite, or the contiguous lacustrine strata. The greater portion of these igneous rocks appear to have originated during the Upper Miocene and Pliocene periods; and extinct quadrupeds of those eras, belonging to the genera Mastodon, Rhinoceros, and others, were buried in ashes and beds of alluvial sand and gravel, which owe their preservation to overspreading sheets of lava.

In Auvergne, the most ancient and conspicuous of the volcanic masses is Mont Dore, which rests immediately on the granitic rocks standing apart from the freshwater strata. This great mountain rises suddenly to the height of several thousand feet above the surrounding platform, and retains the shape of a flattened and somewhat irregular cone, the slope of which is gradually lost in the high plain around. This cone is composed of layers of scoriæ, pumice-stones, and their fine detritus, with interposed beds of trachyte and basalt, which descend often in uninterrupted sheets until they reach and spread

themselves round the base of the mountain.[6] Conglomerates, also, composed of angular and rounded fragments of igneous rocks, are observed to alternate with the above: and the various masses are seen to dip off from the central axis, and to lie parallel to the sloping flanks of the mountain. The summit of Mont Dore terminates in seven or eight rocky peaks, where no regular crater can now be traced, but where we may easily imagine one to have existed, which may have been shattered by earthquakes, and have suffered degradation by aqueous agents. Originally, perhaps, like the highest crater of Etna, it may have formed an insignificant feature in the great pile, and, like it, may frequently have been destroyed and renovated.

Respecting the age of the great mass of Mont Dore, we cannot come at present to any positive decision, because no organic remains have yet been found in the tuffs, except impressions of the leaves of trees of species not yet determined. It has already been stated (p. 217) that the earliest eruptions must have been posterior in origin to those grits and conglomerates of the freshwater formation of the Limagne which contain no pebbles of volcanic rocks. But there is evidence at a few points, as in the hill of Gergovia, presently to be mentioned, that some eruptions took place before the great lakes were drained, while others occurred after the desiccation of those lakes, and when deep valleys had already been excavated through freshwater strata.

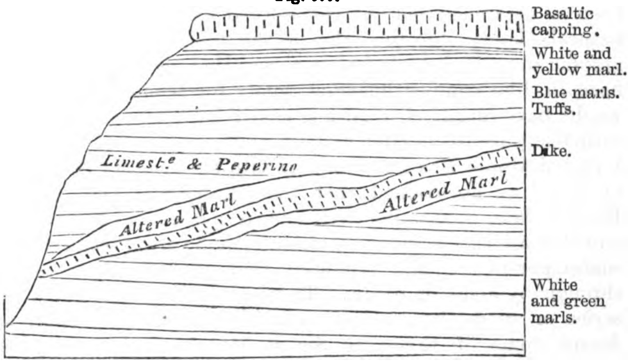
The valley in which the cone of Tartaret, above mentioned (p. 528), is situated affords an impressive monument of the very different dates at which the igneous eruptions of Auvergne have happened; for while the cone itself is of Pleistocene date, the valley is bounded by lofty precipices composed of sheets of ancient columnar trachyte and basalt, which once flowed from the summit of Mont Dore in some part of the Miocene period. These Miocene lavas had accumulated to a thickness of nearly 1,000 feet before the ravine was cut down to the level of the river Couze, a river which was at length dammed up by the modern cone and the upper part of its course transformed into a lake.

Gergovia.—It has been supposed by some observers that there is an alternation of a contemporaneous sheet of lava with freshwater strata in the hill of Gergovia near Clermont. But this idea has arisen from the intrusion of the dike represented in the annexed diagram (fig. 609), which has altered the green and white marls both above and below. Nevertheless, there is a

[6] Scrope's Central France, p. 98.

real alternation of volcanic tuff with strata containing Lower Miocene freshwater shells, among others a Melania allied to *M. inquinata* (fig. 220, p. 251), with a Melanopsis and a Unio; there

Fig. 609.



Hill of Gergovia.

can, therefore, be no doubt that in Auvergne some volcanic explosions took place before the drainage of the lakes, and at a time when the Lower Miocene species of animals and plants still flourished.

Eocene Volcanic Rocks.—*Hebrides.*—It has been shown by Mr. Judd [7] that before the eruption of the Miocene basalts of the Hebrides, great masses of felspathic lavas were poured out from the same vents. But while the basaltic class of lavas spread over vast areas and extended to distances of even fifty or sixty miles from their points of origin, the felspathic lavas have accumulated around the vents themselves, and are usually confined to distances of about ten miles from them; the same differences in the mode of behaviour of streams composed of lavas of the basaltic and felspathic varieties respectively, have been pointed out by Mr. Scrope and other authors in the case of many recent volcanos. From the fact that while on the one hand igneous activity appears to have commenced in the district before the close of the Cretaceous epoch, and on the other that the Miocene basalts lie unconformably upon the earlier felspathic lavas, Mr. Judd is led to regard these latter as representative in a general manner of the Eocene period.

Monte Bolca.—The fissile limestone of Monte Bolca, near Verona, has for many centuries been celebrated in Italy for the number of perfect Ichthyolites which it contains. Agassiz has

[7] Ancient Volcanos of the Highlands, Quart. Geol. Journ., 1874.

described no less than 133 species of fossil fish from this single deposit, and the multitude of individuals by which many of the species are represented, is attested by the variety of specimens treasured up in the principal museums of Europe. They have been all obtained from quarries worked exclusively by lovers of natural history, for the sake of the fossils. Had the lithographic stone of Solenhofen, now regarded as so rich in fossils, been in like manner quarried solely for scientific objects, it would have remained almost a sealed book to paleontologists, so sparsely are the organic remains scattered through it. When I visited Monte Bolca, in company with Sir Roderick Murchison, in 1828, we ascertained that the fish-bearing beds were of Eocene date, containing well-known species of Nummulites, and that a long series of submarine volcanic eruptions, evidently contemporaneous, had produced beds of tuff, which are cut through by dikes of basalt. There is evidence here of a long series of submarine volcanic eruptions of Eocene date, and during some of them, as Sir R. Murchison has suggested, shoals of fish were probably destroyed by the evolution of heat, noxious gases, and tufaceous mud, just as happened when Graham's Island was thrown up between Sicily and Africa in 1831, at which time the waters of the Mediterranean were seen to be charged with red mud, and covered with dead fish over a wide area.[8]

Associated with the marls and limestones of Monte Bolca are beds containing lignite and shale with numerous plants, which have been described by Unger and Massalongo, and referred by them to the Eocene period. I have already cited (p. 245) Professor Heer's remark, that several of the species are common to Monte Bolca and the white clay of Alum Bay, a Middle Eocene deposit; and the same botanist dwells on the tropical character of the flora of Monte Bolca and its distinctness from the subtropical flora of the Lower Miocene of Switzerland and Italy, in which last there is a far more considerable mixture of forms of a temperate climate, such as the willow, poplar, birch, elm, and others. That scarcely any one of the Monte Bolca fish should have been found in any other locality in Europe, is a striking illustration of the extreme imperfection of the paleontological record. We are in the habit of imagining that our insight into the geology of the Eocene period is more than usually perfect, and we are certainly acquainted with an almost unbroken succession of assemblages of shells passing one into the other from the era of the Thanet sands to that of the Bembridge beds or Paris gypsum. The general dearth, therefore, of fish in the

[8] Principles of Geology, chap. xxvii., 11th ed.

different members of the Eocene series, Upper, Middle, and Lower, might induce a hasty reasoner to conclude that there was a poverty of ichthyic forms during this period; but when a local accident, like the volcanic eruptions of Monte Bolca, occurs, proofs are suddenly revealed to us of the richness and variety of this great class of vertebrata in the Eocene sea. The number of genera of Monte Bolca fish is, according to Agassiz, no less than seventy-five, twenty of them peculiar to that locality, and only eight common to the antecedent Cretaceous period. No less than forty-seven out of the seventy-five genera make their appearance for the first time in the Monte Bolca rocks, none of them having been met with as yet in the antecedent formations. They form a great contrast to the fish of the secondary strata, as, with the exception of the Placoids, they are all Teleosteans, only one genus, *Pycnodus*, belonging to the order of Ganoids, which form, as before stated, the vast majority of the ichthyolites entombed in the secondary or Mesozoic rocks.

Cretaceous Period.—M. Virlet, in his account of the geology of the Morea, p. 205, has clearly shown that certain traps in Greece are of Cretaceous date; as those, for example, which alternate conformably with cretaceous limestone and greensand between Kastri and Damala in the Morea. They consist in great part of diallage rocks and serpentine, and of an amygdaloid with calcareous kernels, and a base of serpentine. In certain parts of the Morea, the age of these volcanic rocks is established by the following proofs: first, the lithographic limestones of the Cretaceous era are cut through by trap, and then a conglomerate occurs, at Nauplia and other places, containing in its calcareous cement many well-known fossils of the chalk and greensand, together with pebbles formed of rolled pieces of the same serpentinous trap, which appear in the dikes above alluded to.

Period of Oolite and Lias.—Although the green and serpentinous trap rocks of the Morea belong chiefly to the Cretaceous era, as before mentioned, yet it seems that some eruptions of similar rocks began during the Oolitic period;[9] and it is probable that a large part of the trappean masses, called ophiolites in the Apennines, and associated with the limestone of that chain, are of corresponding age.

Trap of the New Red Sandstone Period.—In the southern part of Devonshire, trappean rocks are associated with New Red Sandstone, and, according to Sir H. De la Beche, have not been intruded subsequently into the sandstone, but were pro-

[9] Boblaye and Virlet, Morea, p. 23.

duced by contemporaneous volcanic action. Some beds of grit, mingled with ordinary red marl, resemble sands ejected from a crater; and in the stratified conglomerates occurring near Tiverton are many angular fragments of trap porphyry, some of them one or two tons in weight, intermingled with pebbles of other rocks. These angular fragments were probably thrown out from volcanic vents, and fell upon sedimentary matter then in the course of deposition.[1]

Trap of the Permian Period.—The recent investigations of Mr. Archibald Geikie in Ayrshire and at Nithsdale in Dumfries-shire have shown that some of the volcanic rocks in that county are of Permian age, and it appears highly probable that the uppermost portion of Arthur's Seat in the suburbs of Edinburgh marks the site of an eruption of the same era.

Trap of the Carboniferous Period.—Two extensive developments of trap rocks occur in the carboniferous basin of the Forth in Scotland. One of these is well exhibited along the shores of Fifeshire, where the igneous masses consist of basalt, sometimes with olivine, and of dolerites. These appear to have been erupted while the sedimentary strata were in a horizontal position, and to have suffered the same dislocations which those strata have subsequently undergone. In the associated volcanic tuffs of this age are found, not only fragments of limestone, shale, flinty slate, and sandstone, but also pieces of coal. Other traps connected with the carboniferous formation may be traced along the south margin of Stratheden, and constitute a ridge parallel with the Ochils, extending from Stirling to near St. Andrews. These consist almost exclusively of dolerite, becoming, in a few instances, earthy and amygdaloidal. They are either interbedded with, or intruded among the sandstone, shale, limestone and ironstone of the Lower Carboniferous. I examined these trap rocks in 1838, in the cliffs south of St. Andrews, where they consist in great part of stratified tuffs, which are curved, vertical, and contorted, like the associated coal-measures. In the tuff I found fragments of carboniferous shale and limestone, and intersecting veins of dolerite.

Fife—Flisk dike.—A trap dike was pointed out to me by Dr. Fleming, in the parish of Flisk, in the northern part of the county of Fife, which cuts through the grey sandstone and shale, forming the lowest part of the Old Red Sandstone, but which may probably be of carboniferous date. It may be traced for many miles, passing through the amygdaloidal and other traps of the hill called Norman's Law in that parish.

[1] De la Beche, Geol. Proceedings, vol. ii. p. 198.

In its course it affords a good exemplification of the passage from the trappean into the plutonic, or highly crystalline texture. Professor Gustav Rose, to whom I submitted specimens of this dike, found it to be dolerite, and composed of greenish black augite and Labrador felspar, the latter being the most abundant ingredient. A small quantity of magnetic iron, perhaps titaniferous, is also present. The result of this analysis is interesting, because both the ancient and modern lavas of Etna consist in like manner of augite, Labradorite, and titaniferous iron.

Erect trees buried in volcanic ash at Arran.—An interesting discovery was made in 1867 by Mr. E. A. Wünsch in the lower carboniferous strata of the north-eastern part of the island of Arran. In the sea-cliff about five miles north of Corrie, near the village of Laggan, strata of volcanic ash occur, forming a solid rock cemented by carbonate of lime and enveloping trunks of trees, determined by Mr. Binney to belong to the genera Sigillaria and Lepidodendron. Some of these trees are at right angles to the planes of stratification, while others are prostrate and accompanied by leaves and fruits of the same genera. I visited the spot in company with Mr. Wünsch in 1870, and saw that the trees with their roots, of which about fourteen had been observed, occur at two distinct levels in volcanic tuffs, parallel to each other, and inclined at an angle of about 40°, having between them beds of shale and coaly matter seven feet thick. It is evident that the trees were overwhelmed by a shower of ashes from some neighbouring volcanic vent, as Pompeii was buried by matter ejected from Vesuvius. The trunks, several of them from three to five feet in circumference, remained with their Stigmarian roots spreading through the stratum below, which had served as a soil. The trees must have continued for years in an upright position after they were killed by the shower of burning ashes, giving time for a partial decay of the interior, so as to afford hollow cylinders into which the spores of plants were wafted. These spores germinated and grew, until finally their stems were petrified by carbonate of lime like some of the remaining portions of the wood of the containing Sigillaria. Mr. Carruthers has discovered that sometimes the plants which had thus grown and become fossil in the inside of a single trunk belonged to several distinct genera. The fact that the tree-bearing deposits now dip at an angle of 40° is the more striking as they must clearly have remained horizontal and undisturbed during a long period of intermittent and contemporaneous volcanic action.

In some of the associated carboniferous shales, ferns and

calamites occur, and all the phenomena of the successive buried forests remind us of the sections (pp. 401, 402) of the Nova Scotia coal-measures, with this difference only, that in the case of the South Joggins, the fossilisation of the trees was effected without the eruption of volcanic matter.

Trap of the Old Red Sandstone Period.—By referring to the section explanatory of the structure of Forfarshire, already given (p. 51), the reader will perceive that beds of conglomerate, No. 3, occur in the middle of the Old Red Sandstone system, 1, 2, 3, 4. The pebbles in these conglomerates are sometimes composed of gneiss and quartzose rocks, sometimes exclusively of different varieties of trap, which last, although purposely omitted in the section referred to, is often found either intruding itself in amorphous masses and dikes into the old fossiliferous tilestones, No. 4, or alternating with them in conformable beds. All the different divisions of the red sandstone, 1, 2, 3, 4, are occasionally intersected by dikes, but they are very rare in Nos. 1 and 2, the upper members of the group consisting of red shale and red sandstone. These phenomena, which occur at the foot of the Grampians, are repeated in the Sidlaw Hills; and it appears that in this part of Scotland volcanic eruptions were most frequent in the earlier part of the Old Red Sandstone period. These lavas are for the most part of the felspathic class, their structure being sometimes porphyritic, at others amygdaloidal; in the latter case the kernels of the latter being sometimes calcareous, often calcedonic, and forming beautiful agates. In a more or less decomposed condition these felspathic lavas are known under the name of claystones. With them occur beds of stratified tuff and conglomerate, stone, compact felspar, and tuff. Some of these rocks look as if they had flowed as lavas over the bottom of the sea, and enveloped quartz pebbles which were lying there, so as to form conglomerates with a base of greenstone, as is seen in Lumley Den, in the Sidlaw Hills. On either side of the axis of this chain of hills (see section, p. 51), the beds of massive trap, and the tuffs composed of volcanic sand and ashes, dip regularly to the south-east or north-west, conformably with the shales and sandstones.

But the geological structure of the Pentland Hills, near Edinburgh, shows that igneous rocks were there formed during the Devonian or 'Old Red' period. These hills are 1,900 feet high above the sea, and consist of conglomerates and sandstones of Devonian age, resting on the inclined edges of grits and slates of Upper Silurian date. The contemporaneous volcanic rocks intercalated in this Old Red Sandstone consist of felspathic

lavas, or felstones, with associated conglomerates and tuffs or ashy beds. The lavas were some of them originally compact, others vesicular, and these last have been converted into amygdaloids. Unlike the lavas of the Tertiary Period in Scotland, they appear to have been of subaqueous rather than of subaërial origin. The evidences of the volcanic origin of the rocks of the Pentland Hills have been well illustrated by Messrs. Maclaren and Geikie.[2]

Silurian volcanic rocks.—It appears from the investigations of Sir R. Murchison in Shropshire, that when the Lower Silurian strata of that country were accumulating, there were frequent volcanic eruptions beneath the sea; and the ashes and scoriæ then ejected gave rise to a peculiar kind of tufaceous sandstone or grit, dissimilar to the other rocks of the Silurian series, and only observable in places where syenitic and other trap rocks protrude. These tuffs occur on the flanks of the Wrekin and Caer Caradoc, and contain Silurian fossils, such as casts of encrinites, trilobites, and mollusca. Although fossiliferous, the stone resembles a sandy claystone of the trap family.[3]

Thin layers of trap, only a few inches thick, alternate in some parts of Shropshire and Montgomeryshire with sedimentary strata of the Lower Silurian system. This trap consists of consolidated felspathic ash with fragments of slate, the beds being traversed by joints like those in the associated sandstone, limestone, and shale, and having the same strike and dip.[4]

In Radnorshire there is an example of twelve bands of stratified trap, alternating with Silurian schists and flagstones, in a thickness of 350 feet. The bedded traps consist of porphyritic felstone, and other varieties; and the interposed Llandeilo flags are of sandstone and shale, with trilobites and graptolites.[5]

The Snowdonian hills in Caernarvonshire consist in great part of volcanic tuffs, the oldest of which are interstratified with the Bala and Llandeilo beds. There are some contemporaneous felspathic lavas of this era, which, says Professor Ramsay, alter the slates on which they repose, having doubtless been poured out over them, in a melted state, whereas the slates which overlie them, having been subsequently deposited after the lava had cooled and consolidated, have entirely escaped alteration. But there are greenstones associated with the same formation, which, although they are often conformable to the slates, are in reality intrusive rocks. They alter the stratified deposits both above and below them, and when traced to great distances, are some-

[2] Maclaren, Geology of Fife and Lothians. Geikie, Trans. Royal Soc. Edinburgh, 1860–1861.

[3] Murchison, Silurian System, &c., p. 230.

[4] Ibid. p. 212.

[5] Ibid. p. 325.

times seen to cut through these slates, and to send off branches. Nevertheless, these greenstones appear to belong, like the lavas, to the Lower Silurian period. In like manner felstones occur contemporaneous with Lower Silurian strata in the Lake District, the Isle of Man, and the S.E. of Ireland.

Cambrian volcanic rocks.—[On the western flank of the Malverns in Herefordshire, some black shales belonging to the Upper Lingula Flags are interstratified with thin sheets of vesicular lava that were probably erupted beneath the sea contemporaneously with the deposition of the muddy sediment. The shales lying beneath the volcanic rock are white, as if calcined from the molten lava, while those lying above have retained their normal black colour. In speaking of this ancient volcanic outburst, Professor Phillips says: 'One might mistake the ferruginous and cellular stone for the subaërial reliquiæ of a volcano in Auvergne,'[6] a district where the erupted volcanic matter is clearly contemporaneous with the associated sedimentary deposits.]

Laurentian volcanic rocks.—The Laurentian rocks in Canada, especially in Ottawa and Argenteuil, are the oldest intrusive masses yet known. They form a set of dikes of a fine-grained dolerite, composed of felspar and pyroxene, with occasional scales of mica and grains of pyrites. Their width varies from a few feet to a hundred yards, and they have a columnar structure, the columns being truly at right angles to the plane with the dike. Some of the dikes send off branches. These dolerites are cut through by intrusive syenite, and this syenite, in its turn, is again cut and penetrated by porphyritic felsite. All these trap rocks appear to be of Laurentian date, as the Cambrian and Huronian rocks rest unconformably upon them.[7] Whether some of the various conformable crystalline rocks of the Laurentian series, such as the coarse-grained granitoid and porphyritic varieties of gneiss, exhibiting scarcely any signs of stratification, and some of the serpentines, may not also be of volcanic origin, is a point very difficult to determine in a region which has undergone so much metamorphic action.

6 Geology of Oxford and the Valley of the Thames, p. 67.
7 Logan, Geology of Canada, 1863.

CHAPTER XXXI.

PLUTONIC ROCKS.

General aspect of plutonic rocks—Granite and its varieties—Decomposing into spherical masses—Rude columnar structure—Graphic granite—Mutual penetration of crystals of quartz and felspar—Glass cavities in quartz of granite—Porphyritic, talcose, and hornblendic granite—Eurite—Syenite—Diorite—Connection of the plutonic with the volcanic rocks—Analogy in composition of trachyte and granite—Granite veins in Glen Tilt, Cape of Good Hope, and Cornwall—Metalliferous veins in strata near their junction with granite—Quartz veins—Exposure of plutonic rocks at the surface due to denudation.

The plutonic rocks may be treated of next in order, as they are most nearly allied to the volcanic class already considered. I have described, in the first chapter, these plutonic rocks as the unstratified division of the crystalline or hypogene formations, and have stated that they differ from the volcanic rocks, not only by their more crystalline texture, but also by the absence of tuffs and breccias, which are the products of eruptions at the earth's surface, whether thrown up into the air or the sea. They differ also by the absence of pores or cellular cavities, to which the expansion of the entangled gases gives rise in ordinary lava, never being scoriaceous or amygdaloidal, nor alternating with tuffs.

From these and other peculiarities it has been inferred that the granites have been formed at considerable depths in the earth, and have cooled and crystallised slowly under great pressure, where the contained gases could not expand. The volcanic rocks, on the contrary, although they also have risen up from below, have cooled from a melted state more rapidly upon or near the surface. From this hypothesis of the great depth at which the granites originated, has been derived the name of 'Plutonic rocks.' The beginner will easily conceive that the influence of subterranean heat may extend downwards from the crater of every active volcano to a great depth below, perhaps several miles or leagues, and the effects which are produced deep in the bowels of the earth may, or rather must, be distinct; so that volcanic and plutonic rocks, each different in texture, and sometimes even in composition, may originate simulta-

neously, the one at the surface, the other far beneath it. The plutonic formations also agree with the volcanic in having veins or ramifications proceeding from central masses into the adjoining rocks, and causing alternations in these last, which will be presently described. They also resemble trap in containing no organic remains; but they differ in being more uniform in texture, whole mountain masses of indefinite extent appearing to have originated under conditions precisely similar.

The two principal members of the Plutonic family of rocks are Granite and Syenite, each of which, with their varieties, bear very much the same relation to each other as the trachytes bear to the basalts. Granite is a compound of felspar, quartz, and mica, the felspars being rich in silica, which forms from 60 to 70 per cent. of the whole aggregate. In syenite quartz is rare or wanting, hornblende taking the place of mica, and the proportion of silica seldom exceeding 60 per cent.

Granite and its varieties.—Granite often preserves a very uniform character throughout a wide range of territory, frequently forming hills of a peculiar rounded form, clad with a scanty vegetation. The surface of the rock is for the most part in a crumbling state, and the hills are often surmounted by piles of stones like the remains of a stratified mass, as in the annexed figure, and sometimes like heaps of boulders, for which they

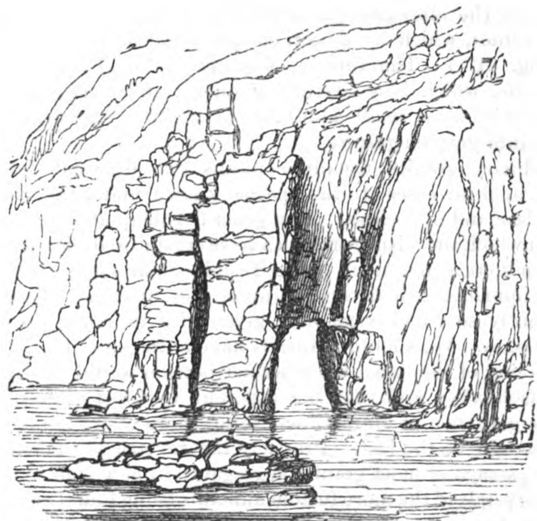
Fig. 610.

Mass of granite near the Sharp Tor, Cornwall.

have been mistaken. The exterior of these stones, originally quadrangular, acquires a rounded form by the action of air and water, for the edges and angles waste away more rapidly than the sides. A similar spherical structure has already been described as characteristic of basalt and other volcanic formations, and it must be referred to analogous causes, as yet but imperfectly understood. Although it is the general peculiarity of granite to assume no definite shapes, it is nevertheless occasionally subdivided by fissures, so as to assume a cuboidal, and even a columnar, structure. Examples of these appearances may be seen near the Land's End in Cornwall. (See fig. 611.)

Felspar, quartz, and mica are considered as the minerals essential to granite, the felspar being most abundant in quan-

Fig. 611.



Granite having a cuboidal and rude columnar structure, Land's End, Cornwall.

tity, and the proportion of quartz exceeding that of mica. These minerals are united in what is termed a confused crystallisation; that is to say, there is no regular arrangement of the crystals in granite, as in gneiss (see fig. 627, p. 577), except in

Fig. 612.

Fig. 613.

Graphic granite.

Fig. 612. Section parallel to the laminæ.
Fig. 613. Section transverse to the laminæ.

the variety termed graphic granite, which occurs mostly in granitic veins. This variety is a compound of felspar and

quartz, so arranged as to produce an imperfect laminar structure. The crystals of felspar appear to have been first formed, leaving between them the space now occupied by the darker-coloured quartz. This mineral, when a section is made at right angles to the alternate plates of felspar and quartz, presents broken lines, which have been compared to Hebrew characters. (See fig. 613.) The variety of granite called by the French *Pegmatite*, which is a mixture of quartz and common felspar, usually with some small admixture of white silvery mica, often passes into graphic granite.

Ordinary granite usually contains two different felspars, which in most cases are the species known under the name of orthoclase and oligoclase. As a general rule quartz serves as a base in which the felspar and mica have crystallised; for although these minerals are much more fusible than silex, they have often imprinted their shapes upon the quartz. This fact, apparently so paradoxical, has given rise to much ingenious speculation. We should naturally have anticipated that, during the cooling of the mass, the siliceous portion would be the first to consolidate; and that the different varieties of felspar, as well as garnets and tourmalines, being more easily liquefied by heat, would be the last. Precisely the reverse has taken place in the passage of most granite aggregates from a fluid to a solid state, crystals of the more fusible minerals being found enveloped in hard, transparent, glassy quartz, which has often taken very faithful casts of each, so as to preserve even the microscopically minute striations on the surface of prisms of tourmaline. Various explanations of this phenomenon have been proposed by MM. de Beaumont, Fournet, and Durocher. They refer to M. Gaudin's experiments on the fusion of quartz, which show that silex, as it cools, has the property of remaining in a viscous state, whereas silicate of alumina never does. This 'gelatinous flint is supposed to retain a considerable degree of plasticity long after the granitic mixture has acquired a low temperature. Occasionally we find the quartz and felspar mutually imprinting their forms on each other, affording evidence of the simultaneous crystallisation of both.'[1]

According to the experiments and observations of Gustav Rose, the quartz of granite has the specific gravity of 2·6, which characterises silica when it is precipitated from a liquid solvent, and not that inferior density, namely 2·3, which belongs to it when it cools in the laboratory, from a state of fusion in what is called the dry way. By some it had been rashly

[1] Bulletin, 2e série, iv. 1304; and D'Archiac, Hist. des Progrès de la Géol., i. 38.

inferred that the manner in which the consolidation of granite takes place is exceedingly different from the cooling of lavas, and that the intense heat supposed to be necessary for the production of mountain masses of plutonic rocks might be dispensed with. But Mr. David Forbes informs me that silica can crystallise in the dry way, and he has found in quartz forming a constituent part of some trachytes, both from Guadaloupe and Iceland, glass cavities quite similar to those met with in genuine volcanic minerals.

These 'glass cavities,' which with many other kindred phenomena have been carefully studied by Mr. Sorby, are those in which a liquid, on cooling, has become first viscous and then solid without crystallising or undergoing a definite change in its physical structure. Other cavities which, like those just mentioned, are frequently discernible under the microscope in the minerals composing granitic rocks, are filled some of them with gas or vapour, others with liquid, and by the movements of the bubbles thus included the distinctness of such cavities from those filled with a glassy substance can be tested. Mr. Sorby admits that the frequent occurrence of fluid cavities in the quartz of granite implies that water was almost always present in the formation of this rock; but the same may be said of almost all lavas, and it is now more than forty years since Mr. Scrope insisted on the important part which water plays in volcanic eruptions, being so intimately mixed up with the materials of the lava that he supposed it to aid in giving mobility to the fluid mass. It is well known that steam escapes for months, sometimes for years, from the cavities of lava when it is cooling and consolidating. As to the result of Mr. Sorby's experiments and speculations on this difficult subject, they may be stated in a few words. He concludes that the physical conditions under which the volcanic and granitic rocks originate are so far similar that in both cases they combine igneous fusion, aqueous solution, and gaseous sublimation—the proof, he says, of the operation of water in the formation of granite being quite as strong as of that of heat.[2]

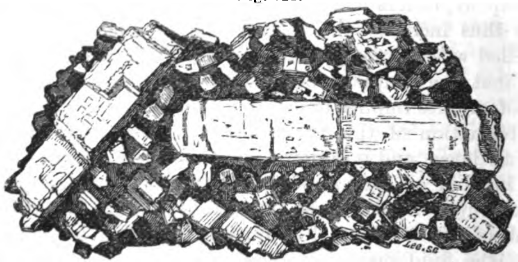
When rocks are melted at great depths water must be present, for two reasons—First, because rain-water and sea-water are always descending through fissured and porous rocks, and must at length find their way into the regions of subterranean heat; and secondly, because in a state of combination water enters largely into the composition of some of the most common minerals, especially those of the aluminous class. But the

[2] See Quart. Geol. Journ., vol. xiv. pp. 465, 488.

existence of water under great pressure affords no argument against our attributing an excessively high temperature to the mass with which it is mixed up. Bunsen, indeed, imagines that in Iceland water attains a white heat at a very moderate depth. To what extent some of the metamorphic rocks containing the same minerals as the granites may have been formed by hydrothermal action without the intervention of intense heat comparable to that brought into play in a volcanic eruption, will be considered when we treat of the metamorphic rocks in the thirty-third chapter.

Porphyritic granite.—This name has been sometimes given to that variety in which large crystals of felspar, usually orthoclase, sometimes more than 3 inches in length, are scattered through an ordinary base of granite. An example of this texture may be seen in the granite of the Land's End, in Cornwall (fig. 614).

Fig. 614.



Porphyritic granite, Land's End, Cornwall.

The two larger prismatic crystals in this drawing represent orthoclase felspar, smaller crystals of which are also seen, similar in form, scattered through the base. In this base also appear black specks of mica, the crystals of which have a more or less perfect hexagonal outline. The remainder of the mass is quartz, the translucency of which is strongly contrasted to the opacity of the white felspar and black mica. But neither the transparency of the quartz nor the silvery lustre of the mica can be expressed in the engraving.

The uniform mineral character of large masses of granite seems to indicate that large quantities of the component elements were thoroughly mixed up together, and then united into crystallised minerals under precisely similar conditions. There are, however, many accidental, or 'accessory' minerals, as they are termed, which occur in granite. Among these black schorl or tourmaline, actinolite, zircon, garnet, iron-pyrites, sphene, apatite, and fluor-spar are not uncommon; but they are as a general

rule too sparingly dispersed to modify the general aspect of the rock. They show, nevertheless, that the ingredients were not everywhere exactly the same; and a still greater difference may be traced in the ever-varying proportions of the felspar, quartz, and mica.

Talcose granite, or Protogine of French authors, a rock very abundant in the Alps, is a granite, or sometimes only a highly metamorphic form of gneiss, which contains in addition to the ordinary minerals varying quantities of a substance formerly supposed to be talc, but which may be altered mica.

Felsite, or *Eurite*, is a rock which in chemical composition differs little from many trachytes and granites. The matrix of the rock has a compact appearance, consisting of an intimate mixture of felspar and quartz imperfectly crystallised, and is commonly of a light colour. It is often porphyritic, containing crystals of felspar (usually orthoclase) and quartz, the latter mineral being very variable in quantity. Felsites containing much quartz are often called *Quartz-porphyry*, and when only felspar crystals are present *Orthoclase-porphyry*, the name felsite being reserved for the non-porphyritic varieties. A rock in which oligoclase appears to replace orthoclase felspar, and from which quartz is absent, is generally termed *porphyrite*, though the name is objectionable. It is abundant in the Pentland and Ochil Hills in Scotland. All these species are comprehended in the one term *Felstone*. They appear to occupy an intermediate position between the trachytes and the truly crystalline granites, a circumstance which affords one of many arguments in favour of what is now the prevailing opinion, that the granites are also of igneous origin.

Hornblendic granite.—The quadruple compound of quartz, felspar, mica, and hornblende may be so termed, and form a passage between granite and quartziferous syenite. This rock occurs at Mount Sorrel in Leicestershire, and in Scotland and Guernsey.

Syenite.—Syenite is the name given to rocks composed of orthoclase felspar and hornblende with occasionally some quartz and mica; it usually contains more than 55 but rarely above 60 per cent. of silica. Although its name is derived from the celebrated quarries of Syene in Egypt, more recent researches have shown that the rock there is in reality a hornblendic granite. *Miascite*, so called from Miask in the Ural Mountains, and *Zircon syenite*, are both varieties of syenite which contain nepheline; the latter being further characterised by the presence of crystals of zircon.

Diorite is a rock made up of triclinic felspar, usually oligoclase,

with hornblende and occasionally a little quartz; it contains still less silica than syenite.

Diabase.—This term is given to a mixture of triclinic felspar, augite and a little chlorite, containing about 50 per cent. of silica. This rock is extremely abundant in North Wales, where, in the vicinity of Dolgelly, amongst other varieties, the so-called uralite porphyry is met with, in which the augite is in part replaced by uralite, a mineral already alluded to (pp. 498, 502).

Gabbro or *Euphotide* is also a rock composed of triclinic felspar and diallage, in which olivine is frequently present. It is also called diallage rock, and is well exhibited near the Lizard Promontory in Cornwall. One variety contains smaragdite, which is usually regarded as a variety of hornblende. This rock is closely allied both to hyperite or hypersthene rock.

Connection of the plutonic with the volcanic rocks.—The minerals which constitute alike the plutonic and volcanic rocks consist, almost exclusively, of seven constituents—namely, silica, alumina, magnesia, lime, soda, potash, and oxide of iron (Table, p. 498). In making chemical analyses of specimens obtained in the field the student may often be perplexed by finding that these constituents appear to exist in equal proportions in very different classes of rocks. But Mr. David Forbes has pointed out in an admirable pamphlet on Chemical Geology that this arises from the inexperience of the geologist in choosing the typical portion to be examined; for example, when diorite (composed of felspar and hornblende) is erupted through quartzose strata it will usually absorb more or less of quartz particles, thus becoming apparently a syenite (a mixture of felspar, hornblende and quartz); yet the mass of the erupted rock, except at points of contact, is unquestionably a diorite, and a microscopic examination of the quartziferous portion will show that the quartz had become entangled in the erupted mass, and was not an original constituent of it. It may thus often happen that small specimens roughly named by the geologist porphyry, granite, syenite, mica-schist and gneiss, might be pronounced by the chemist identical in chemical composition, whereas the truth would be that all these specimens were in reality miscalled, being merely abnormal varieties altered in appearance and composition by exceptional influences.[3]

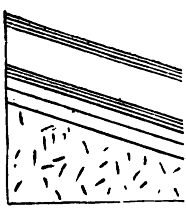
'The ordinary granite of Aberdeenshire,' says Dr. MacCulloch, 'is the usual ternary compound of quartz, felspar, and mica; though sometimes hornblende is substituted for the mica. But in many places a variety occurs which is composed simply of felspar and hornblende; and in examining more minutely this

[3] Forbes, Study of Chemical Geology, 1866.

duplicate compound, it is observed in some places to assume a fine grain, and at length to become undistinguishable from the greenstones of the trap family. It also passes in the same uninterrupted manner into a basalt, and at length into a soft claystone, with a schistose tendency on exposure, in no respect differing from those of the trap islands of the western coast.'[4] In Hungary there are varieties of trachyte, which, geologically speaking, are of modern origin, in which crystals, not only of mica, but of quartz, are common, together with felspar and hornblende. It is easy to conceive how such volcanic masses may, at a certain depth from the surface, pass downwards into granite.

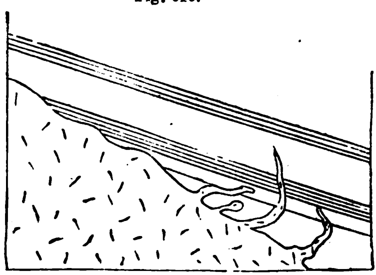
Granitic veins.—I have already hinted at the close analogy in the forms of certain granitic and trappean veins; and it will be found that strata penetrated by plutonic rocks have suffered changes very similar to those exhibited near the contact of volcanic dikes. Thus, in Glen Tilt, in Scotland, alternating strata of limestone and argillaceous schist come in contact with a mass of granite. The contact does not take place as might have been looked for, if the granite had been formed there before the strata were deposited, in which case the section would have appeared as in fig. 615; but the union is as represented in fig. 616, the undulating outline of the granite intersecting different

Fig. 615.



Section as it would appear if the strata had been deposited on the granite.

Fig. 616.



Junction of granite and argillaceous schist in Glen Tilt. (MacCulloch.)[5]

strata, and occasionally intruding itself in tortuous veins into the beds of clay-slate and limestone, from which it differs so remarkably in composition. The limestone is sometimes changed in character by the proximity of the granitic mass or its veins, and acquires a more compact texture, like that of hornstone or

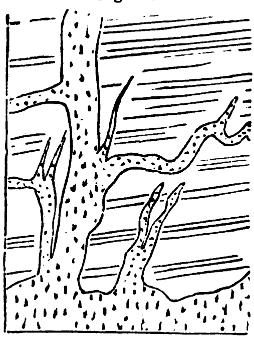
[4] Syst. of Geol., vol. i. pp. 157 and 158.
[5] Geol. Trans., First Series, vol. iii. pl. 21.

chert, with a splintery fracture, and effervescing slowly with acids.

The conversion of the limestone in these and many other instances into a siliceous rock, effervescing slowly with acids, would be difficult of explanation, were it not ascertained that such limestones are always impure, containing grains of quartz, mica, or felspar disseminated through them. The elements of these minerals, when the rock has been subjected to great heat, may have been fused, and so spread more uniformly through the whole mass.

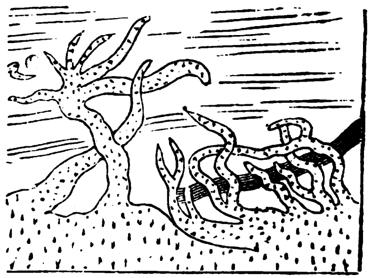
In the plutonic, as in the volcanic rocks, there is every gradation from a tortuous vein to the most regular form of a dike, such as intersect the tuffs and lavas of Vesuvius and Etna.

Fig. 617.



Granite veins traversing clay slate, Table Mountain, Cape of Good Hope.[6]

Fig. 618.



Granite veins traversing gneiss, Cape Wrath. (MacCulloch.)[7]

Dikes of granite may be seen, among other places, on the southern flank of Mount Battock, one of the Grampians, the opposite walls sometimes preserving an exact parallelism for a considerable distance. As a general rule, however, granite veins in all quarters of the globe are more sinuous in their course than those of trap. They present similar shapes at the most northern point of Scotland, and the southernmost extremity of Africa, as the annexed drawings will show.

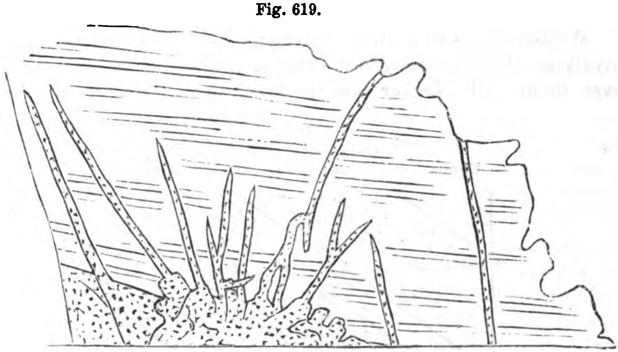
It is not uncommon for one set of granite veins to intersect another ; and sometimes there are three sets, as in the environs of Heidelberg, where the granite on the banks of the river Neckar is seen to consist of three varieties, differing in colour, grain, and various peculiarities of mineral composition. One

[6] Capt. B. Hall, Trans. Roy. Soc. Edinburgh, vol. vii.
[7] Western Islands, pl. 31.

of these, which is evidently the second in age, is seen to cut through an older granite; and another, still newer, traverses both the second and the first. In Shetland there are two kinds of granite. One of them, composed of hornblende, mica, felspar, and quartz, is of a dark colour, and is seen underlying gneiss. The other is a red granite, which penetrates the dark variety everywhere in veins.[8]

Fig. 619 is a sketch of a group of granite veins in Cornwall, given by Messrs. Von Oeynhausen and Von Dechen.[9] The main body of the granite here is of a porphyritic appearance, with large crystals of felspar; but in the veins it is fine-grained,

Fig. 619.



Granite veins passing through hornblende slate, Carnsilver Cove, Cornwall.

and without these large crystals. The general height of the veins is from 16 to 20 feet, but some are much higher.

The granites, syenites, diorites, granitic felsites, and indeed all plutonic rocks, are frequently observed to contain metallic veins at or near their junction with stratified formations. On the other hand, similar veins which traverse stratified rocks are, as a general law, more metalliferous near such junctions than in other positions. Hence it has been inferred that these metals may have been spread in a gaseous form through the fused mass, and that the contact of another rock, in a different state of temperature, or sometimes the existence of rents in other rocks in the vicinity, may have caused the sublimation of the metals.[1]

Veins of pure quartz are often found in granite as in many stratified rocks, but they are not traceable, like veins of granite or trap, to large bodies of rock of similar composition. They appear to have been cracks, into which siliceous matter was

[8] MacCulloch, Syst. of Geol., vol. i. p. 58.

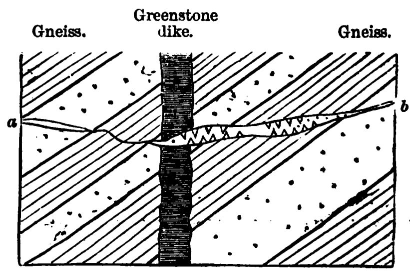
[9] Phil. Mag. and Annals, No. 27, New Series, March 1829.

[1] Necker, Proceedings of Geol. Soc. No. 26, p. 392.

infiltrated. Such segregation, as it is called, can sometimes clearly be shown to have taken place long subsequently to the original consolidation of the containing rock. Thus, for example, I observed in the gneiss of Tronstad Strand, near Drammen, in Norway, the annexed section on the beach. It appears that the alternating strata of whitish graniteform gneiss and black hornblende schist were first cut through by a greenstone dike, about 2½ feet wide; then the crack *a*, *b*, passed through all these rocks, and was filled up with quartz. The opposite walls of the veins are in some parts incrusted with transparent crystals of quartz, the middle of the vein being filled up with common opaque white quartz.

We have seen that the volcanic formations have been called overlying, because they not only penetrate others but spread over them. M. Necker has proposed to call the granites the

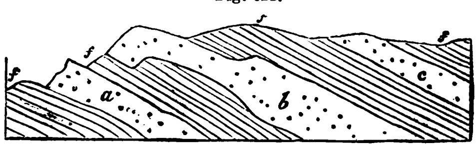
Fig. 620.



a, *b*. Quartz vein passing through gneiss and greenstone, Tronstadt Strand, near Christiania.

underlying igneous rocks, and the distinction here indicated is highly characteristic. It was indeed supposed by some of the earlier observers, that the granite of Christiania, in Norway, was intercalated in mountain masses between the primary or

Fig. 621.



Porphyritic eurite alternating with primary fossiliferous strata, near Christiania.

palæozoic strata of that country, so as to overlie fossiliferous shale and limestone. But although the granite sends veins into these fossiliferous rocks, and is decidedly posterior in origin, its

actual superposition in mass has been disproved by Professor Keilhau, whose observations on this controverted point I had opportunities in 1837 of verifying. There are, however, on a smaller scale, certain beds of porphyritic eurite, some a few feet, others many yards in thickness, which pass into granite, and deserve perhaps to be classed as plutonic rather than trappean rocks, which may truly be described as interposed conformably between fossiliferous strata, as the eurites (*a*, *c*, fig. 621), which divide the bituminous shales and argillaceous limestones, *f f*. But some of these same eurites are partially unconformable, as *b*, and may lead us to suspect that the others also, notwithstanding their appearance of interstratification, have been forcibly injected. Some of the porphyritic rocks above mentioned are highly quartzose, others very felspathic. In proportion as the masses are more voluminous, they become more granitic in their texture, less conformable, and even begin to send forth veins into contiguous strata. In a word, we have here a beautiful illustration of the intermediate gradations between volcanic and plutonic rocks, not only in their mineralogical composition and structure, but also in their relations of position to associated formations. If the term 'overlying' can in this instance be applied to a plutonic rock, it is only in proportion as that rock begins to acquire a trappean aspect.

It has been already hinted that the heat, which in every active volcano extends downwards to indefinite depths, must produce simultaneously very different effects near the surface and far below it; and we cannot suppose that rocks resulting from the crystallising of fused matter under a pressure of several thousand feet, much less several miles, of the earth's crust can exactly resemble those formed at or near the surface. Hence the production at great depths of a class of rocks analogous to the volcanic, and yet differing in many particulars, might have been predicted, even had we no plutonic formations to account for. How well these agree, both in their positive and negative characters, with the theory of their deep subterranean origin, the student will be able to judge by considering the descriptions already given.

It has, however, been objected, that if the granitic and volcanic rocks were simply different parts of one great series, we ought to find in mountain chains volcanic dikes passing upwards into lava and downwards into granite. But we may answer that our vertical sections are usually of small extent; and if we find in certain places a transition from trap to porous lava, and in others a passage from granite to trap, it is as much as could be expected of this evidence.

The prodigious extent of denudation which has been already demonstrated to have occurred at former periods will reconcile the student to the belief that crystalline rocks of high antiquity, although deep in the earth's crust when originally formed, may have become uncovered and exposed at the surface. Their actual elevation above the sea may be referred to the same causes to which we have attributed the upheaval of marine strata, even to the summits of some mountain chains.

CHAPTER XXXII.

ON THE DIFFERENT AGES OF THE PLUTONIC ROCKS.

Difficulty in ascertaining the precise age of a plutonic rock—Test of age by relative position—Test by intrusion and alteration—Test by mineral composition—Test by included fragments—Recent and Pliocene plutonic rocks, why invisible—Miocene syenite of the Isle of Skye—Eocene plutonic rocks in the Andes—Granite altering Cretaceous rocks—Granite altering Lias in the Alps—Granite of Dartmoor altering Carboniferous strata—Granite of the Old Red Sandstone Period—Syenite altering Silurian strata in Norway—Blending of the same with gneiss—Most ancient plutonic rocks—Granite protruded in a solid form.

When we adopt the igneous theory of granite, as explained in the last chapter, and believe that different plutonic rocks have originated at successive periods beneath the surface of the planet, we must be prepared to encounter greater difficulty in ascertaining the precise age of such rocks, than in the case of volcanic and fossiliferous formations. We must bear in mind, that the evidence of the age of each contemporaneous volcanic rock was derived, either from lavas poured out upon the ancient surface, whether in the sea or in the atmosphere, or from tuffs and conglomerates, also deposited at the surface, and either containing organic remains themselves, or intercalated between strata containing fossils. But the same tests entirely fail or are only applicable in a modified degree when we endeavour to fix the chronology of a rock which has crystallised from a state of fusion in the bowels of the earth. In that case, we are reduced to the tests of relative position, intrusion, alteration of the rocks in contact, included fragments, and mineral character; but all these may yield at best a somewhat ambiguous result.

Test of age by relative position.—Unaltered fossiliferous strata of every age are met with reposing immediately on plutonic rocks; as at Christiania, in Norway, where the Pleistocene deposits, and at Heidelberg, on the Neckar, and Mount Sorrel in Leicestershire, where the New Red Sandstone formations rest on granite. In these, and similar instances, inferiority in position is connected with the superior antiquity of granite. The crystalline rock was solid before the sedimentary

beds were superimposed, and the latter usually contain in them rounded pebbles of the subjacent granite.

Test by intrusion and alteration.—But when plutonic rocks send veins into strata, and alter them near the point of contact, in the manner before described (p. 559), it is clear that, like intrusive traps, they are newer than the strata which they invade and alter. Examples of the application of this test will be given in the sequel.

Test by mineral composition.—Notwithstanding a general uniformity in the aspect of plutonic rocks, we have seen in the last chapter that there are many varieties, such as hornblendic granite, talcose granite, and others. One of these varieties is sometimes found exclusively prevailing throughout an extensive region, where it preserves a homogeneous character; so that, having ascertained its relative age in one place, we can recognise its identity in others, and thus determine from a single section the chronological relations of large mountain masses. Having observed, for example, that the syenite of Norway, in which the mineral called zircon abounds, has altered the Silurian strata wherever it is in contact, we do not hesitate to refer other masses of the same zircon-syenite in the south of Norway to a post-Silurian date. Some have imagined that the age of different granites might, to a great extent, be determined by their mineral characters alone; granite with hornblende, for instance, being more modern than common or micaceous granite. But modern investigations have proved these generalisations to have been premature.

Test by included fragments.—This criterion can rarely be of much importance, because the fragments involved in granite are usually so much altered, that they cannot be referred with certainty to the rocks whence they were derived. In the White Mountains, in North America, according to Professor Hubbard, a granite vein, traversing granite, contains fragments of slate and trap which must have fallen into the fissure when the fused materials of the vein were injected from below,[1] and thus the granite is shown to be newer than those slaty and trappean formations from which the fragments were derived.

Recent and Pliocene plutonic rocks, why invisible.—The explanations already given in the twenty-eighth and in the last chapter of the probable relation of the plutonic to the volcanic formations, will naturally lead the reader to infer that rocks of the one class can never be produced at or near the surface without some members of the other being formed below. It is not uncommon for lava-streams to require more than ten years

[1] Silliman's Journ., No. 69, p. 123.

to cool in the open air; and where they are of great depth, a much longer period. The melted matter poured from Jorullo, in Mexico, in the year 1759, which accumulated in some places to the height of 550 feet, was found to retain a high temperature half a century after the eruption.[2] We may conceive, therefore, that great masses of subterranean lava may remain in a red-hot or incandescent state in the volcanic foci for immense periods, and the process of refrigeration may be extremely gradual. Sometimes, indeed, this process may be retarded for an indefinite period, by the accession of fresh supplies of heat: for we find that the lava in the crater of Stromboli, one of the Lipari Islands, has been in a state of constant ebullition for the last two thousand years; and we may suppose this fluid mass to communicate with some caldron or reservoir of fused matter below. In the Isle of Bourbon, also, where there has been an emission of lava once in every two years for a long period, the lava below can scarcely fail to have been permanently in a state of liquefaction. If then it be a reasonable conjecture, that about 2,000 volcanic eruptions occur in the course of every century, either above the waters of the sea or beneath them,[3] it will follow that the quantity of plutonic rock generated, or in progress during the Recent epoch, must already have been considerable.

But as the plutonic rocks originate at some depth in the earth's crust, they can only be rendered accessible to human observation by subsequent upheaval and denudation. Between the period when a plutonic rock crystallises in the subterranean regions and the era of its protrusion at any single point of the surface, one or two geological periods must usually intervene. Hence, we must not expect to find the Recent or even the Pliocene granites laid open to view, unless we are prepared to assume that sufficient time has elapsed since the commencement of the Pliocene period for great upheaval and denudation. A plutonic rock, therefore, must, in general, be of considerable antiquity relatively to the fossiliferous and volcanic formations, before it becomes extensively visible. As we know that the upheaval of land has been sometimes accompanied in South America by volcanic eruptions and the emission of lava, we may conceive the more ancient plutonic rocks to be forced upwards to the surface by the newer rocks of the same class formed successively below,—subterposition in the plutonic, like superposition in the sedimentary rocks, being usually characteristic of a newer origin.

[2] See 'Principles,' *Index*, 'Jorullo.'
[3] Ibid., 'Volcanic Eruptions.'

In the accompanying diagram (fig. 622), an attempt is made to show the inverted order in which sedimentary and plutonic for-

Fig. 622.

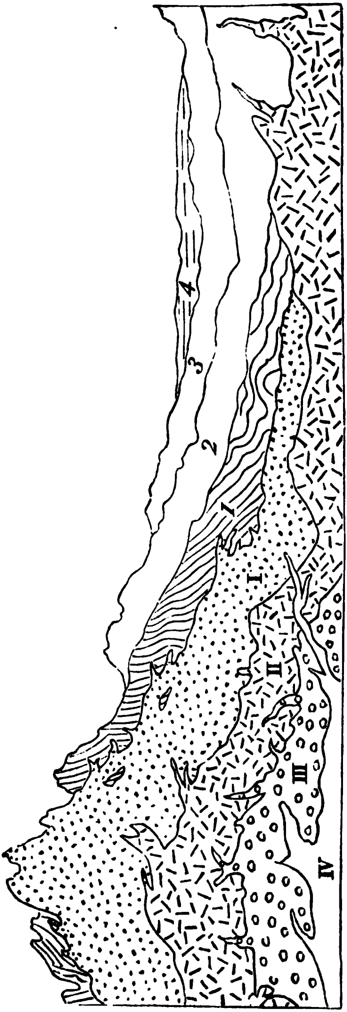


Diagram showing the relative position which the plutonic and sedimentary formations of different ages may occupy.

I. Primary plutonic rocks.
II. Secondary plutonic rocks.
III. Tertiary plutonic rocks.
IV. Post-tertiary plutonic rocks.

1. Primary fossiliferous or Palæozoic strata.
2. Secondary or Mesozoic strata.
3. Tertiary or Cainozoic strata.
4. Post-tertiary strata.

The metamorphic rocks are not indicated in this diagram; but the student will infer, from what is said in Chaps. XXXI. and XXXIII., that some portions of the stratified formations, Nos. 1 and 2, invaded by granite, will have become metamorphic.

mations may occur in the earth's crust. The oldest plutonic rock, No. I., has been upheaved at successive periods until it

has become exposed to view in a mountain-chain. This protrusion of No. I. has been caused by the igneous agency which produced the newer plutonic rocks Nos. II., III., and IV. Part of the primary fossiliferous strata, No. I., have also been raised to the surface by the same gradual process. It will be observed that the Recent *strata* No. 4 and the Recent *granite* or plutonic rock No. IV. are the most remote from each other in position, although of contemporaneous date. According to this hypothesis, the convulsions of many periods will be required before Recent or Post-tertiary granite will be upraised so as to form the highest ridges and central axes of mountain-chains. During that time the *Recent* strata No. 4 might be covered by a great many newer sedimentary formations.

Tertiary plutonic rocks.—At many different points in the Hebrides, as in Skye, Mull, Rum, St. Kilda, &c., great masses of granite and syenite are found in close association with the Tertiary volcanic rocks which have been before described.[4] Dr. MacCulloch described the syenites of Skye as intersecting limestone and shale which are of the age of the lias. The limestone, which at a greater distance from the granite contains shells, exhibits no traces of them near its junction, where it has been converted into a highly crystalline marble.

MacCulloch pointed out that the granite and syenite here, as in Raasay, was newer than the secondary strata of these islands, and Prof. A. Geikie afterwards showed that in Mull there are strong grounds for believing these granites and syenites to be of Tertiary age, like the volcanic rocks with which they are so intimately associated. Professor Zirkel, of Leipsic, has discovered that both in Mull and Skye there are great mountain masses of intrusive rocks, consisting of gabbro containing much olivine, which have been erupted subsequently to the granites. In Skye these gabbros constitute the remarkable Cuchullin Hills, which are so famed for their wild and majestic scenery. And lastly Mr. Judd has shown that the great mountain groups in the Hebrides, composed of granites and gabbros, constitute the relics of five grand volcanos which were in eruption during a great part of the Tertiary period, the earlier formed masses of granite being connected with the series of felspathic lavas probably of Eocene age; while the gabbros, which break through the granites, are the consolidated reservoirs that gave rise to the great streams of basaltic lava of Miocene age, which constitute the plateaux forming so large a portion of the Hebridean Archipelago. These researches show that the western isles of Scotland afford a most admirable and instructive series of illus-

[4] Judd, 'Ancient Volcanoes of the Highlands,' Geol. Soc., Jan. 1874.

trations of the intimate connection between the rocks of the volcanic and the plutonic classes respectively; and at the same time of the perfect identity in their nature and sequence, of the phenomena of volcanic activity during former periods of the earth's history, and those which are exhibited to us at the present day. There are strong grounds for believing that the granites of Arran and the Mourne Mountains in Ireland are of the same age as those of Skye, Mull, Rum, &c.[5]

In a former part of this volume (p. 260), the great nummulitic formation of the Alps and Pyrenees was referred to the Eocene period, and it follows that vast movements which have raised those fossiliferous rocks from the level of the sea to the height of more than 10,000 feet above its level have taken place since the commencement of the Tertiary epoch. Here, therefore, if anywhere, we might expect to find hypogene formations of Eocene date breaking out in the central axis or most disturbed region of the loftiest chain in Europe. Accordingly, in the Swiss Alps, even the *flysch*, or upper portion of the nummulitic series, has been occasionally invaded by plutonic rocks, and converted into crystalline schists of the hypogene class. There can be little doubt that even the talcose granite or gneiss of Mont Blanc itself has been in a fused or pasty state since the *flysch* was deposited at the bottom of the sea; and the question as to its age is not so much whether it be a secondary or tertiary granite or gneiss, as whether it should be assigned to the Eocene or Miocene epoch.

Great upheaving movements have been experienced in the region of the Andes, during the Post-tertiary period. In some part, therefore, of this chain, we may expect to discover tertiary plutonic rocks laid open to view; and Mr. Darwin's account of the Chilian Andes, to which the reader may refer, fully realises this expectation.

But the theory adopted in this work of the subterranean origin of the hypogene formations would be untenable, if the supposed fact here alluded to, of the appearance of tertiary granite at the surface, was not a rare exception to the general rule. A considerable lapse of time must intervene between the formation of plutonic and metamorphic rocks in the nether regions, and their emergence at the surface. For a long series of subterranean movements must occur before such rocks can be uplifted into the atmosphere or the ocean; and, before they can be rendered visible to man, some strata which previously covered them must have been stripped off by denudation.

We know that in the Bay of Baiæ in 1538, in Cutch in 1819,

[5] Judd, 'Ancient Volcanoes of the Highlands,' Geol. Soc., Jan. 1874.

and on several occasions in Peru and Chili, since the commencement of the present century, the permanent upheaval or subsidence of land has been accompanied by the simultaneous emission of lava at one or more points in the same volcanic region. From these and other examples it may be inferred that the rising or sinking of the earth's crust, operations by which sea is converted into land, and land into sea, are a part only of the consequences of subterranean igneous action. It can scarcely be doubted that this action consists, in a great degree, of the baking, and occasionally the liquefaction, of rocks, causing them to assume, in some cases a larger, in others a smaller volume than before the application of heat. It consists also in the generation of gases, and their expansion by heat, and the injection of liquid matter into rents formed in superincumbent rocks. The prodigious scale on which these subterranean causes have operated in Sicily since the deposition of the Newer Pliocene strata will be appreciated, when we remember that throughout half the surface of that island such strata are met with, raised to the height of from 50 to that of 2,000 and even 3,000 feet above the level of the sea. In the same island also the older rocks which are contiguous to these marine tertiary strata must have undergone, within the same period, a similar amount of upheaval.

The like observations may be extended to nearly the whole of Europe, for, since the commencement of the Eocene Period, the entire European area, including some of the central and very lofty portions of the Alps themselves, as I have elsewhere shown,[6] has, with the exception of a few districts, emerged from the deep to its present altitude. There must, therefore, have been at great depths in the earth's crust, within the same period, an amount of subterranean change, corresponding to this vast alteration of level affecting a whole continent.

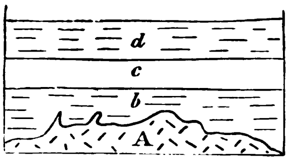
The principal effect of subterranean movements during the Tertiary Period seems to have consisted in the upheaval of hypogene formations of an age anterior to the Carboniferous. The repetition of another series of movements, of equal violence, might upraise the plutonic and metamorphic rocks of many secondary periods; and, if the same force should still continue to act, the next convulsions might bring up to the day the *tertiary* and *recent* hypogene rocks. In the course of such changes many of the existing sedimentary strata would suffer greatly by denudation, others might assume a metamorphic structure, or become melted down into plutonic and volcanic rocks. Meanwhile the deposition of a great thickness of new

[6] See map of Europe and explanation, in Principles, book i.

strata would not fail to take place during the upheaval and partial destruction of the older rocks. But I must refer the reader to the last chapter but one of this volume for a fuller explanation of these views.

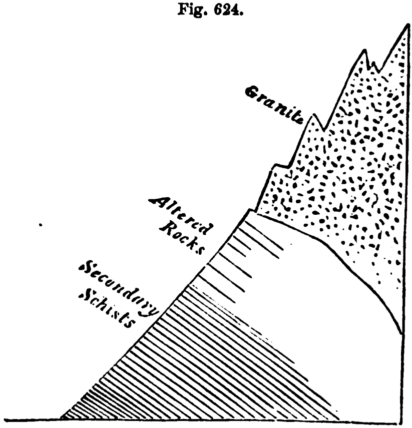
Plutonic rocks of Cretaceous Period.—It will be shown in the next chapter that chalk, as well as lias, has been altered by granite in the eastern Pyrenees. Whether such granite be cretaceous or tertiary cannot easily be decided. Suppose *b*, *c*, *d*, fig. 623, to be three members of the Cretaceous series, the lowest of which, *b*, has been altered by the granite A, the modifying influence not having extended so far as *c*, or having but slightly affected its lowest beds. Now it can rarely be possible for the geologist to decide whether the beds *d* existed at the time of the intrusion of A, and alteration of *b* and *c*, or whether they were subsequently thrown down upon *c*. But as some Cretaceous and even tertiary rocks have been raised to the height of more than 9,000 feet in the Pyrenees, we must not assume that plutonic formations of the same periods may not have been brought up and exposed by denudation, at the height of 2,000 or 3,000 feet on the flanks of that chain.

Fig. 623.



Plutonic rocks of the Oolite and Lias.—In the Department of the Hautes-Alpes, in France, M. Élie de Beaumont traced a black argillaceous limestone, charged with belemnites, to within a few yards of a mass of granite. Here the limestone begins to put on a granular texture, but is extremely fine-grained. When nearer the junction it becomes grey, and has a saccharoid structure. In another locality, near Champoleon, a granite composed of quartz, black mica, and rose-coloured felspar is

Fig. 624.



Junction of granite with Jurassic or Oolite strata in the Alps, near Champoleon.

observed partly to overlie the secondary rocks, producing an alteration which extends for about 30 feet downwards, diminishing in the beds which lie farthest from the granite. (See fig. 624.) In the altered mass the argillaceous beds are hardened, the limestone is saccharoid, the grits quartzose, and in the midst of them is a thin layer of an imperfect granite. It is also an important circumstance that near the point of contact, both the granite and the secondary rocks become metalliferous, and contain nests and small veins of blende, galena, iron, and copper pyrites. The stratified rocks become harder and more crystalline, but the granite, on the contrary, softer and less perfectly crystallised near the junction.[7] Although the granite is incumbent in the above section (fig. 624), we cannot assume that it overflowed the strata, for the disturbances of the rocks are so great in this part of the Alps that their original position is often inverted.

Plutonic rocks of Carboniferous Period.—The granite of Dartmoor, in Devonshire, was formerly supposed to be one of the most ancient of the plutonic rocks, but is now ascertained to be posterior in date to the culm-measures of that county, which from their position, and as containing true coal-plants, are now known to be members of the true Carboniferous series. This granite, like the hornblendic granite of Christiania, has broken through the stratified formations, on the north-west side of Dartmoor, the successive members of the culm-measures abutting against the granite, and becoming metamorphosed as they approach it. These strata are also penetrated by granite veins, and plutonic dikes, called 'elvans.'[8] The granite of Cornwall is probably of the same date, and, therefore, as modern as the Carboniferous strata, if not newer.

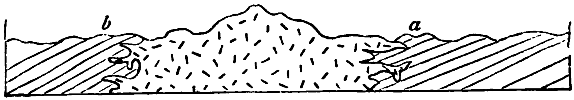
Plutonic rocks of Silurian Period.—It has long been known that a very ancient granite near Christiania, in Norway, is posterior in date to the Lower Silurian strata of that region, although its exact position in the Palæozoic series cannot be defined. Von Buch first announced, in 1813, that it was of newer origin than certain limestones containing orthocerata and trilobites. The proofs consist in the penetration of granite veins into the shale and limestone, and the alteration of the strata, for a considerable distance from the point of contact, both of these veins and the central mass from which they emanate. (See p. 562.) Von Buch supposed that the plutonic rock alternated with the fossiliferous strata, and that large masses of granite were some-

[7] Élie de Beaumont, Sur les Montagnes de l'Oisans, &c. Mém. de la Soc. d'Hist. Nat. de Paris, tom. v.

[8] Proceed. Geol. Soc., vol. ii. p. 562; and Trans., 2nd ser. vol. v. p. 686.

times incumbent upon the strata; but this idea was erroneous, and arose from the fact that the beds of shale and limestone often dip towards the granite up to the point of contact, appearing as if they would pass under it in mass, as at *a*, fig. 625,

Fig. 625.

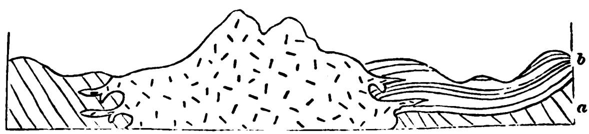


and then again on the opposite side of the same mountain, as at *b*, dip away from the same granite. When the junctions, however, are carefully examined, it is found that the plutonic rock intrudes itself in veins and nowhere covers the fossiliferous strata in large overlying masses, as is so commonly the case with trappean formations.[9]

Now this granite, which is more modern than the Silurian strata of Norway, also sends veins in the same country into an ancient formation of gneiss; and the relations of the plutonic rock and the gneiss, at their junction, are full of interest when we duly consider the wide difference of epoch which must have separated their origin.

The length of this interval of time is attested by the following facts:—The fossiliferous, or Silurian, beds rest unconformably upon the truncated edges of the gneiss, the inclined strata of which had been denuded before the sedimentary beds were superimposed (see fig. 626). The signs of denudation are two-

Fig. 626.



Granite sending veins into Silurian strata and gneiss, Christiania, Norway.
a. Inclined gneiss. *b*. Silurian strata.

fold; first, the surface of the gneiss is seen occasionally, on the removal of the newer beds containing organic remains, to be worn and smoothed; secondly, pebbles of gneiss have been found in some of these Silurian strata. Between the origin, therefore, of the gneiss and the granite there intervened, first, the period when the strata of gneiss were denuded; secondly,

[9] See the Gæa Norvegica and other works of Keilhau, with whom I examined this country.

the period of the deposition of the Silurian deposits upon the denuded and inclined gneiss *a*. Yet the granite produced after this long interval is often so intimately blended with the ancient gneiss, at the point of junction, that it is impossible to draw any other than an arbitrary line of separation between them; and where this is not the case, tortuous veins of granite pass freely through gneiss, ending sometimes in threads, as if the older rock had offered no resistance to their passage. These appearances may probably be due to hydrothermal action (see below, p. 583). I shall merely observe in this place that had such junctions alone been visible, and had we not learnt, from other sections, how long a period elapsed between the consolidation of the gneiss, and the injection of this granite, we might have suspected that the gneiss was scarcely solidified, or had not yet assumed its complete metamorphic character when invaded by the plutonic rock. From this example we may learn how impossible it is to conjecture whether certain granites in Scotland, and other countries, which send veins into gneiss and other metamorphic rocks, are primary, or whether they may not belong to some secondary or tertiary period.

Oldest granites.—It is not half a century since the doctrine was very general that all granitic rocks were *primitive*, that is to say, that they originated before the deposition of the first sedimentary strata, and before the creation of organic beings (see above, p. 10). But so greatly are our views now changed, that we find it no easy task to point out a single mass of granite demonstrably more ancient than known fossiliferous deposits. Could we discover some Laurentian strata resting immediately on granite, there being no alterations at the point of contact, nor any intersecting granitic veins, we might then affirm the plutonic rock to have originated before the oldest known fossiliferous strata. Still it would be presumptuous, as we have already pointed out (p. 462), to suppose that when a small part only of the globe has been investigated, we are acquainted with the oldest fossiliferous strata in the crust of our planet. Even when these are found we cannot assume that there never were any antecedent strata containing organic remains, which may have become metamorphic. If we find pebbles of granite in a conglomerate of the Lower Laurentian system, we may then feel assured that the parent granite was formed before the Laurentian formation. But if the incumbent strata be merely Cambrian or Silurian, the fundamental granite, although of high antiquity, may be posterior in date to *known* fossiliferous formations.

CHAPTER XXXIII.

METAMORPHIC ROCKS.

General character of metamorphic rocks—Gneiss—Hornblende-schist—Serpentine—Mica-schist—Clay-slate—Quartzite—Chlorite-schist—Metamorphic limestone—Origin of the metamorphic strata—Their stratification—Fossiliferous strata near intrusive masses of granite converted into rocks identical with different members of the metamorphic series—Arguments hence derived as to the nature of plutonic action—Hydrothermal action, or the influence of steam and gases in producing metamorphism—Objections to the metamorphic theory considered.

We have now considered three distinct classes of rocks: first, the aqueous, or fossiliferous; secondly, the volcanic; and thirdly, the plutonic; and it remains for us to examine those crystalline (or hypogene) strata to which the name of *metamorphic* has been assigned. The last-mentioned term expresses, as before explained, a theoretical opinion that such strata, after having been deposited from water, acquired, by the influence of heat and other causes, a highly crystalline texture. They who still question this opinion may call the rocks under consideration the stratified hypogene formations or crystalline schists.

These rocks, when in their characteristic or normal state, are wholly devoid of organic remains, and contain no distinct fragments of other rocks, whether rounded or angular. They sometimes break out in the central parts of mountain chains, but in other cases extend over areas of vast dimensions, occupying, for example, nearly the whole of Norway and Sweden, where, as in Brazil, they appear alike in the lower and higher grounds. However crystalline these rocks may become in certain regions, they never, like granite or trap, send veins into contiguous formations. In Great Britain, those members of the series which approach most nearly to granite in their composition, as gneiss, mica-schist, and hornblende-schist, are chiefly found in the country north of the rivers Forth and Clyde.

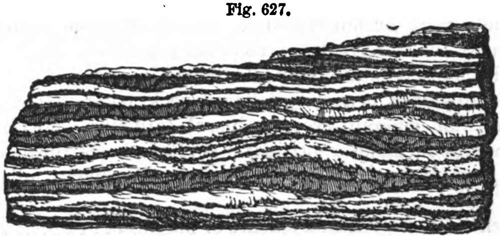
Many attempts have been made to trace a general order of succession or superposition in the members of this family; clay-slate, for example, having been often supposed to hold in-

variably a higher geological position than mica-schist, and mica-schist to overlie gneiss. But although such an order may prevail throughout limited districts, it is by no means universal. To this subject, however, I shall again revert, in Chapter XXXV., where the chronological relations of the metamorphic rocks are pointed out.

Principal metamorphic rocks.—The following may be enumerated as the principal members of the metamorphic class:—gneiss, mica-schist, hornblende-schist, clay-slate, chlorite-schist, hypogene or metamorphic limestone, and certain kinds of quartz-rock or quartzite.

Gneiss.—The first of these, gneiss, may be called stratified—or by those who object to that term, foliated—granite, being formed of the same materials as granite, namely, felspar, quartz, and mica. In the specimen here figured, the white layers consist almost exclusively of granular felspar, with here and there a speck of mica and grain of quartz. The dark layers are composed of grey quartz and black mica, with occasionally a grain of felspar intermixed. The rock splits most easily in the plane

Fig. 627.



Fragment of gneiss, natural size; section made at right angles to the planes of foliation.

of these darker layers, and the surface thus exposed is almost entirely covered with shining spangles of mica. The accompanying quartz, however, greatly predominates in quantity, but the most ready cleavage is determined by the abundance of mica in certain parts of the dark layer. Instead of consisting of these thin laminæ, gneiss is sometimes simply divided into thick beds, in which the mica has only a slight degree of parallelism to the planes of stratification.

Hand specimens may often be obtained from such gneiss which are undistinguishable from granite, affording an argument to which we shall allude in the concluding part of this chapter, in favour of those who regard all granite and syenite not as igneous rocks, but as aqueous formations so altered as to have lost all signs of their original stratified arrangement. Gneiss in

geology is commonly used to designate not merely stratified and foliated rocks having the same component materials as granite or syenite, but also in a wider sense to embrace the formation with which other members of the metamorphic series such as hornblende-schist may alternate, and which are then considered subordinate to the true gneiss.

The different varieties of rock allied to gneiss, into which felspar enters as an essential ingredient, will be understood by referring to what was said of granite. Thus, for example, hornblende may be superadded to mica, quartz, and felspar, forming a hornblendic or syenitic gneiss; or talc may be substituted for mica, constituting talcose gneiss (called stratified protogine by the French), a rock composed of felspar, quartz, and talc, in distinct crystals or grains.

Hornblende-schist is usually black, and composed principally of hornblende, with a variable quantity of felspar, and sometimes grains of quartz. When the hornblende and felspar are in nearly equal quantities, and the rock is not slaty, it corresponds in character with the greenstones of the trap family, and has been called 'primitive greenstone.' It may be termed hornblende rock or amphibolite. Some of these hornblendic masses may really have been volcanic rocks, which have since assumed a more crystalline or metamorphic texture.

Actinolite-schist is a slaty foliated rock, composed chiefly of actinolite, an emerald-green mineral (allied to hornblende), which occurs in slender prismatic crystals, sometimes forming radiating groups, with some admixture of quartz, mica, and garnet.

Serpentine is a hydrated silicate of magnesia in which there is sometimes from 30 to 40 per cent. of magnesia. It is a rock of a green colour, sometimes rendered of a mottled red and dark brown by the presence of hematite. It enters largely into the composition of a trap dike cutting through Old Red Sandstone in Forfarshire, and in that case is probably an altered basaltic dike which had contained much olivine. The theory of its having been originally a volcanic product subsequently altered by metamorphism may at first sight seem inconsistent with its occurrence in large and regularly stratified masses in the metamorphic series in Scotland, as in Aberdeenshire. But it has been suggested in explanation that such serpentine may have been originally regularly-bedded trap tuff, and volcanic breccia, with much olivine, which would still retain a stratified appearance after their conversion into a metamorphic rock.

Mica-schist, or *Micaceous schist*, is, next to gneiss, one of the most abundant rocks of the metamorphic series. It is slaty,

essentially composed of mica and quartz, the mica sometimes appearing to constitute the whole mass. Beds of pure quartz also occur in this formation. In some districts, garnets in regular twelve-sided crystals form an integrant part of mica-schist. This rock passes by insensible gradations into clay-slate.

Clay-slate—Argillaceous schist—Argillite.—This rock sometimes resembles an indurated clay or shale. It is for the most part extremely fissile, often affording good roofing-slate. Occasionally it derives a shining and silky lustre from the minute particles of mica or talc which it contains. It varies from greenish or bluish-grey to a lead colour ; and it may be said of this, more than of any other schist, that it is common to the metamorphic and fossiliferous series, for some clay-slates taken from each division would not be distinguishable by mineral characters alone. It is not uncommon to meet with an argillaceous rock having the same composition, without the slaty cleavage, which may be called argillite.

Chlorite-schist is a green slaty rock, in which chlorite is abundant in foliated plates, usually blended with minute grains of quartz, or sometimes with felspar or mica ; often associated with, and graduating into, gneiss and clay-slate.

Quartzite, or *Quartz rock*, is an aggregate of grains of quartz which are either in minute crystals, or in many cases slightly rounded, occurring in regular strata associated with gneiss or other metamorphic rocks. Compact quartz, like that so frequently found in veins, is also found together with granular quartzite. Both of these alternate with gneiss or mica-schist, or pass into those rocks by the addition of mica, or of felspar and mica.

Crystalline or *Metamorphic limestone*.—This rock, called by the earlier geologists *primary limestone*, is sometimes a white crystalline granular marble, which when in thick beds can be used in sculpture ; but more frequently it occurs in thin beds, forming a foliated schist much resembling in colour and arrangement certain varieties of gneiss and mica-schist. When it alternates with these rocks, it often contains some crystals of mica, and occasionally quartz, felspar, hornblende, talc, chlorite, garnet, and other minerals. It enters sparingly into the structure of the metamorphic districts of Norway, Sweden, and Scotland, but is largely developed in the Alps.

Origin of the Metamorphic strata.—Having said thus much of the mineral composition of the metamorphic rocks, I may combine what remains to be said of their structure and history with an account of the opinions entertained of their

probable origin. At the same time, it may be well to forewarn the reader that we are here entering upon ground of controversy, and soon reach the limits where positive induction ends, and beyond which we can only indulge in speculations. It was once a favourite doctrine, and is still maintained by many, that these rocks owe their crystalline texture, their want of all signs of a mechanical origin, or of fossil contents, to a peculiar and nascent condition of the planet at the period of their formation. The arguments in refutation of this hypothesis will be more fully considered when I show, in Chapter XXXV., to how many different ages the metamorphic formations are referable, and how gneiss, mica-schist, clay-slate, and hypogene limestone (that of Carrara, for example) have been formed, not only since the first introduction of organic beings into this planet, but even long after many distinct races of plants and animals had flourished and passed away in succession.

The doctrine respecting the crystalline strata, implied in the name metamorphic, may properly be treated of in this place; and we must first inquire whether these rocks are really entitled to be called stratified in the strict sense of having been originally deposited as sediment from water. The general adoption by geologists of the term stratified, as applied to these rocks, sufficiently attests their division into beds very analogous, at least in form, to ordinary fossiliferous strata. This resemblance is by no means confined to the existence in both occasionally of a laminated structure, but extends to every kind of arrangement which is compatible with the absence of fossils, and of sand, pebbles, ripple-mark, and other characters which the metamorphic theory supposes to have been obliterated by plutonic action. Thus, for example, we behold alike in the crystalline and fossiliferous formations an alternation of beds varying greatly in composition, colour, and thickness. We observe, for instance, gneiss alternating with layers of black hornblende-schist, or of green chlorite-schist, or with granular quartz, or limestone; and the interchange of these different strata may be repeated for an indefinite number of times. In the like manner, mica-schist alternates with chlorite-schist, and with beds of pure quartz or of granular limestone. We have already seen that, near the immediate contact of granitic veins and volcanic dikes, very extraordinary alterations in rocks have taken place, more especially in the neighbourhood of granite. It will be useful here to add other illustrations, showing that a texture undistinguishable from that which characterises the more crystalline metamorphic formations has actually been superinduced in strata once fossiliferous.

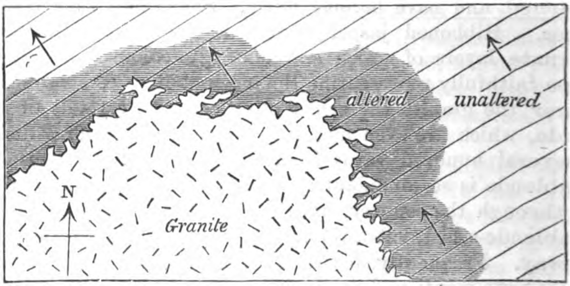
Fossiliferous strata rendered metamorphic by intrusive masses of Granite.—In the southern extremity of Norway there is a large district, on the west side of the fiord of Christiania, which I visited in 1837 with the late Professor Keilhau, in which hornblendic granite protrudes in mountain masses through fossiliferous strata, and usually sends veins into them at the point of contact. The stratified rocks, replete with shells and zoophytes, consist chiefly of shale, limestone, and some sandstone, and all these are invariably altered near the granite for a distance of from 50 to 400 yards. The aluminous shales are hardened, and have become flinty. Sometimes they resemble jasper. Ribboned jasper is produced by the hardening of alternate layers of green and chocolate-coloured schist, each stripe faithfully representing the original lines of stratification. Nearer the granite the schist often contains crystals of hornblende, which are even met with in some places for a distance of several hundred yards from the junction; and this black hornblende is so abundant that eminent geologists, when passing through the country, have confounded it with the ancient hornblende-schist, subordinate to the great gneiss-formation of Norway. Frequently, between the granite and the hornblende slate above mentioned, grains of mica and crystalline felspar appear in the schist, so that rocks resembling gneiss and mica-schist are produced. Fossils can rarely be detected in these schists, and they are more completely effaced in proportion to the more crystalline texture of the beds, and their vicinity to the granite. In some places the siliceous matter of the schist becomes a granular quartzite; and when hornblende and mica are added, the altered rock loses its stratification, and passes into a kind of granite. The limestone, which at points remote from the granite is of an earthy texture and blue colour, and often abounds in corals, becomes a white granular marble near the granite, sometimes siliceous, the granular structure extending occasionally upwards of 400 yards from the junction; the corals being for the most part obliterated, though sometimes preserved, even in the white marble. Both the altered limestone and hardened slate contain garnets in many places, also ores of iron, lead, and copper, with some silver. These alterations occur equally, whether the granite invades the strata in a line parallel to the general strike of the fossiliferous beds, or in a line at right angles to their strike, both of which modes of junction will be seen by the accompanying ground plan (fig. 628).[1]

The granite of Cornwall sends forth veins into a coarse

[1] Keilhau, Gæa Norvegica, pp. 61–63.

argillaceous-schist, provincially termed killas. This killas is converted into hornblende-schist near the contact with the veins. These appearances are well seen at the junction of the granite and killas, in St. Michael's Mount, a small island nearly 300 feet high, situated in the bay, at a distance of about three miles from Penzance. The granite of Dartmoor, in Devonshire, says Sir H. De la Beche, has intruded itself into the carboniferous slate and slaty sandstone, twisting and contorting the strata, and sending veins into them. Hence some of the slate rocks

Fig. 628.



Ground-plan of altered slate and limestone near granite, Christiania.
The arrows indicate the dip, and the oblique lines the strike of the beds.

have become 'micaceous;' others more indurated, and with the characters of mica-slate and gneiss; while others again appear converted into a hard zoned rock strongly impregnated with felspar.'[2]

Nowhere, however, are the phenomena of local metamorphism more beautifully illustrated than in the Western Isles of Scotland. Mr. Judd has pointed out that in this neighbourhood great masses of granite and gabbro were, during the Tertiary period, thrust through the various Palæozoic and Secondary strata, and in the vicinity of the junctions of the igneous and the sedimentary masses the most instructive examples of metamorphism may be witnessed. Thus Lias limestones crowded with fossil shells are found losing, as we approach the igneous rocks, all traces of their organic remains, and at last passing into a highly crystalline or saccharoid marble suitable for statuary purposes; similarly clays and limestones, under like conditions, are also found to be deprived of every trace of the organic structures in them and to graduate into indurated slaty rock and quartzite respectively, while the felspathic sandstones of the Cambrian are altered to a highly micaceous schistose rock.

[2] Geol. Manual, p. 479.

We learn from the investigations of M. Dufrénoy, that in the eastern Pyrenees there are mountain masses of granite posterior in date to the formations called lias and chalk of that district, and that these fossiliferous rocks are greatly altered in texture, and often charged with iron-ore, in the neighbourhood of the granite. Thus in the environs of St. Martin, near St. Paul de Fénouillet, the chalky limestone becomes more crystalline and saccharoid as it approaches the granite, and loses all trace of the fossils which it previously contained in abundance. At some points, also, it becomes dolomitic, and filled with small veins of carbonate of iron, and spots of red iron-ore. At Rancié the lias nearest the granite is not only filled with iron-ore, but charged with pyrites, tremolite, garnet, and a new mineral somewhat allied to felspar, called from the place in the Pyrenees where it occurs 'couzeranite.'

The Lower Silurian strata of the Highlands, which are throughout their whole mass changed into various metamorphic rocks, are found near their junction with the intrusive masses of the Grampian Mountains to have undergone a further metamorphism of a local character.

We have seen that sedimentary rocks in the immediate proximity of great igneous intrusions are found to have undergone great induration, while along their planes of bedding or cleavage the development of various crystalline minerals has frequently taken place. The similarity of the rocks thus formed to many of the foliated or schistose rocks suggests that the latter may have been in all cases produced from pre-existing strata, by the action of analogous chemical forces, operating on a more extended scale. Thus gneiss and mica-schist may be nothing more than altered micaceous and argillaceous sandstones, granular quartzite may have been derived from siliceous sandstone, and compact quartzite may be the last stage of alteration of the same materials. Similarly, clay-slate may be altered shale, and granular marble may have originated in the form of ordinary limestone, replete with shells and corals, which have since been obliterated; and, lastly, calcareous sands and marls may have been changed into impure crystalline limestones.

The anthracite and plumbago associated with hypogene rocks may have been coal; for not only is coal converted into anthracite in the vicinity of some trap dikes, but we have seen that a like change has taken place generally even far from the contact of igneous rocks, in the disturbed region of the Appalachians. At Worcester, in the state of Massachusetts, 45 miles due west of Boston, a bed of plumbago and impure anthracite occurs,

interstratified with mica schist. It is about 2 feet in thickness, and has been made use of both as fuel and in the manufacture of lead pencils. At the distance of 30 miles from the plumbago, there occurs, on the borders of Rhode Island, an impure anthracite in slates containing impressions of coal-plants of the genera *Pecopteris*, *Neuropteris*, *Calamites*, &c. This anthracite is intermediate in character between that of Pennsylvania and the plumbago of Worcester, in which last the gaseous or volatile matter (hydrogen, oxygen, and nitrogen) is to the carbon only in the proportion of 3 per cent. After traversing the country in various directions, I came to the conclusion that the Carboniferous shales or slates with anthracite and plants, which in Rhode Island often pass into mica-schists, have at Worcester assumed a perfectly crystalline and metamorphic texture; the anthracite having been nearly transmuted into that state of pure carbon which is called plumbago or graphite.[3]

Now the alterations above described as superinduced in rocks by volcanic dikes and granite veins prove incontestably that powers exist in nature capable of transforming fossiliferous into crystalline strata, a very few simple elements constituting the component materials not common to both classes of rocks. These elements, which are enumerated in our Table, p. 498, may be made to form new combinations by what has been termed plutonic action, or those chemical changes which are no doubt connected with the passage of heat, and usually heated steam and waters, through the strata.

Hydrothermal action, or the influence of Steam and Gases in producing Metamorphism.—The experiments of Gregory Watt, in fusing rocks in the laboratory, and allowing them to consolidate by slow cooling, prove distinctly that a rock need not be perfectly melted in order that a re-arrangement of its component particles should take place, and a partial crystallisation ensue.[4] We may easily suppose, therefore, that all traces of shells and other organic remains may be destroyed; and that new chemical combinations may arise, without the mass being so fused as that the lines of stratification should be wholly obliterated. We must not, however, imagine that heat alone, such as may be applied to a stone in the open air, can constitute all that is comprised in plutonic action. We know that volcanos in eruption not only emit fluid lava, but give off steam and other heated gases, which rush out in enormous volume, for days, weeks, or years continuously, and are even disengaged from lava during its consolidation.

[3] See Lyell, Quart. Geol. Journ., vol. i. p. 199.
[4] Phil. Trans., 1804.

We also know that long after volcanos have spent their force, hot springs continue for ages to flow out at various points in the same area. In regions also subject to violent earthquakes such springs are frequently observed issuing from rents, usually along lines of fault or displacement of the rocks. These thermal waters are most commonly charged with a variety of mineral ingredients, and they retain a remarkable uniformity of temperature from century to century. A like uniformity is also persistent in the nature of the earthy, metallic, and gaseous substances with which they are impregnated. It is well ascertained that springs, whether hot or cold, charged with carbonic acid, and especially with hydrofluoric acid, which is often present in small quantities, are powerful causes of decomposition and chemical reaction in rocks through which they percolate.

The changes which Daubrée has shown to have been produced by the alkaline waters of Plombières in the Vosges, are more especially instructive.[5] These waters have a heat of 160° F., or an excess of 109° above the average temperature of ordinary springs in that district. They were conveyed by the Romans to baths through long conduits or aqueducts. The foundations of some of their works consisted of a bed of concrete made of lime, fragments of brick, and sandstone. Through this and other masonry the hot waters have been percolating for centuries, and have given rise to various zeolites—apophyllite and chabazite among others; also to calcareous spar, arragonite, and fluor spar, together with siliceous minerals, such as opal—all found in the interspaces of the bricks and mortar, or constituting part of their re-arranged materials. The quantity of heat brought into action in this instance in the course of 2,000 years has, no doubt, been enormous, but the intensity of it developed at any one moment has been always inconsiderable.

From these facts and from the experiments and observations of Sénarmont, Daubrée, Delesse, Scheerer, Sorby, Sterry Hunt, and others, we are led to infer that when there are large volumes of matter in the bowels of the earth, containing water and various acids intensely heated under enormous pressure, these subterranean fluid masses will gradually part with their heat by the escape of steam and various gases through fissures, producing hot springs; or by the passage of the same through the pores of the overlying and injected rocks. Even the most compact rocks may be regarded, before they have been exposed to the air and dried, in the light of sponges filled with water. According to the experiments of Henry, water, under an hydrostatic pressure of 96 feet, will absorb three times as much

[5] Daubrée, Sur le Métamorphisme. Paris, 1860.

carbonic acid gas as it can under the ordinary pressure of the atmosphere. There are other gases, as well as the carbonic acid, which water absorbs, and more rapidly in proportion to the amount of pressure. Although the gaseous matter first absorbed would soon be condensed, and part with its heat, yet the continual arrival of fresh supplies from below might, in the course of ages, cause the temperature of the water, and with it that of the containing rock, to be materially raised; the water acts not only as a vehicle of heat, but also by its affinity for various silicates, which, when some of the materials of the invaded rocks are decomposed, form quartz, felspar, mica, and other minerals. As for quartz, it can be produced under the influence of heat by water holding alkaline silicates in solution, as in the case of the Plombières springs. The quantity of water required, according to Daubrée, to produce great transformations in the mineral structure of rocks, is very small. As to the heat required, silicates may be produced in the moist way at about incipient red heat, whereas to form the same in the dry way would require a much higher temperature.

M. Fournet, in his description of the metalliferous gneiss near Clermont, in Auvergne, states that all the minute fissures of the rock are quite saturated with free carbonic acid gas; which gas rises plentifully from the soil there and in many parts of the surrounding country. The various elements of the gneiss, with the exception of the quartz, are all softened; and new combinations of the acid with lime, iron, and manganese are continually in progress.[6]

The power of subterranean gases is well illustrated by the stufas of St. Calogero in the Lipari Islands, where the horizontal strata of tuff forming cliffs 200 feet high have been discoloured in places by the jets of steam often above the boiling point, called 'stufas,' issuing from the fissures; and similar instances are recorded by M. Virlet of corrosion of rocks near Corinth, and by Dr. Daubeny of decomposition of trachytic rocks by sulphuretted hydrogen and muriatic acid gases in the Solfatara, near Naples. In all these instances it is clear that the gaseous fluids must have made their way through vast thicknesses of porous or fissured rocks, and their modifying influence may spread through the crust for thousands of yards in thickness.

It has been urged as an argument against the metamorphic theory, that rocks have a small power of conducting heat, and it is true that when dry, and in the air, they differ remarkably from metals in this respect. The syenite of Norway, as we have

[6] See Principles, *Index*, 'Carbonated Springs,' &c.

seen, p. 561, has sometimes altered fossiliferous strata both in the direction of their dip and strike for a distance of a quarter of a mile; but the theory of gneiss and mica-schist above proposed requires us to imagine that the same influence has extended through strata miles in thickness. Professor Bischoff has shown what changes may be superinduced, on black marble and other rocks, by the steam of a hot spring having a temperature of no more than 133° to 167° Fahr., and we are becoming more and more acquainted with the prominent part which water is playing in distributing the heat of the interior through mountain masses of incumbent strata, and of introducing into them various mineral elements in a fluid or gaseous state. Such facts may induce us to consider whether many granites and other rocks of that class may not sometimes represent merely the extreme of a similar slow metamorphism. But, on the other hand, the heat of lava in a volcanic crater when it is white and glowing like the sun must convince us that the temperature of a column of such a fluid at the depth of many miles exceeds any heat which can ever be witnessed at the surface. That large portions of the plutonic rocks had been formed under the influence of such intense heat is in perfect accordance with their great volume, uniform composition, and absence of stratification. The forcing also of veins into contiguous stratified or schistose rocks is a natural consequence of the hydrostatic pressure to which columns of molten matter many miles in height must give rise.

Objections to the metamorphic theory considered.—It has been objected to the metamorphic theory that the crystalline schists contain a considerable proportion of potash and soda, whilst the sedimentary strata out of which they are supposed to have been formed are usually wanting in alkaline matter. But this reasoning proceeds on mistaken data, for clay, marl, shale, and slate often contain a considerable proportion of alkali, so much so as to make them frequently unfit to be burnt into bricks or pottery, and the Old Red Sandstone in Forfarshire and other parts of Scotland derived from disintegration of granite, contains much triturated felspar rich in potash. In the common salt by which strata are often largely impregnated, as in Patagonia, much soda is present, and potash enters largely into the composition of fossil sea-weeds; and recent analysis has also shown that the carboniferous strata in England, the Upper and Lower Silurian in East Canada, and the oldest clay-states in Norway, all contain as much alkali as is generally present in metamorphic rocks.

Another objection has been derived from the alternation of highly crystalline strata with others less crystalline. The heat,

it is said, in its ascent from below, must have traversed the less altered schists before it reached a higher and more crystalline bed. In answer to this, it may be observed, that if a number of strata differing greatly in composition from each other be subjected to equal quantities of heat, or hydrothermal action, there is every probability that some will be much more fusible or soluble than others. Some, for example, will contain soda, potash, lime, or some other ingredient capable of acting as a flux or solvent; while others may be destitute of the same elements, and so refractory as to be very slightly affected by the same causes. Nor should it be forgotten that, as a general rule, the less crystalline rocks do really occur in the upper, and the more crystalline in the lower part of each metamorphic series.

CHAPTER XXXIV.

METAMORPHIC ROCKS—*continued.*

Definition of slaty cleavage and joints—Supposed causes of these structures—Crystalline theory of cleavage—Mechanical theory of cleavage—Condensation and elongation of slate rocks by lateral pressure—Lamination of some volcanic rocks due to motion—Whether the foliation of the crystalline schists be usually parallel with the original planes of stratification—Examples in Norway and Scotland—Causes of irregularity in the planes of foliation.

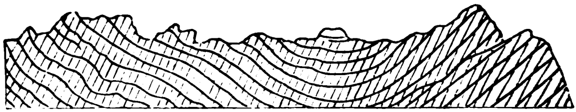
We have already seen that chemical forces of great intensity have frequently acted upon sedimentary and fossiliferous strata long subsequently to their consolidation, and we may next inquire whether the component minerals of the altered rocks usually arrange themselves in planes parallel to the original planes of stratification, or whether, after crystallisation, they more commonly take up a different position.

In order to estimate fairly the merits of this question, we must first define what is meant by the terms cleavage and foliation. There are four distinct forms of structure exhibited in rocks, namely, stratification, joints, slaty cleavage, and foliation; and all these must have different names, even though there be cases where it is impossible, after carefully studying the appearances, to decide upon the class to which they belong.

Slaty cleavage.—Professor Sedgwick, whose essay 'On the Structure of Large Mineral Masses' first cleared the way towards a better understanding of this difficult subject, observes, that joints are distinguishable from lines of slaty cleavage in this, that the rock intervening between two joints has no tendency to cleave in a direction parallel to the planes of the joints, whereas a rock is capable of indefinite subdivision in the direction of its slaty cleavage. In cases where the strata are curved, the planes of cleavage are still perfectly parallel. This has been observed in the slate rocks of part of Wales (see fig. 629), which consist of a hard greenish slate. The true bedding is there indicated by a number of parallel stripes, some of a lighter and some of a darker colour than the general mass. Such stripes are found to be parallel to the true planes of stratification, wherever these are manifested by ripple-mark, or by beds con-

taining peculiar organic remains. Some of the contorted strata are of a coarse mechanical structure, alternating with fine-grained crystalline chloritic slates, in which case the same slaty

Fig. 629.

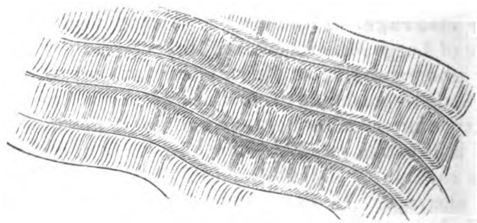


Parallel planes of cleavage intersecting curved strata. (Sedgwick.)

cleavage extends through the coarser and finer beds, though it is brought out in greater perfection in proportion as the materials of the rock are fine and homogeneous. It is only when these are very coarse that the cleavage planes entirely vanish. In the Welsh hills these planes are usually inclined at a very considerable angle to the planes of the strata, the average angle being as much as from 30° to 40°. Sometimes the cleavage planes dip towards the same point of the compass as those of stratification, but often to opposite points.[1] The cleavage, as represented in fig. 629, is generally constant over the whole of any area affected by one great set of disturbances, as if the same lateral pressure which caused the crumpling up of the rock along parallel, anticlinal, and synclinal axes caused also the cleavage.

Professor McKenny Hughes remarks, that where a rough cleavage cuts flagstones at a considerable angle to the planes of stratification, the rock often splits into large slabs, across which the lines of bedding are frequently seen, but when the cleavage planes approach within about 15° of stratification,

Fig. 630.



Section in Lower Silurian slates of Cardiganshire, showing the cleavage planes bent along the junction of the beds. (T. McK. Hughes.)

the rock is apt to split along the lines of bedding. He has also called my attention to the fact that subsequent movements in a cleaved rock sometimes drag and bend the cleavage planes along

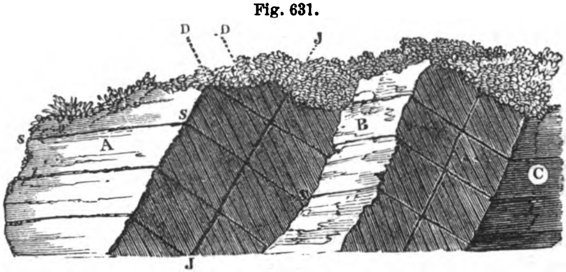
[1] Geol. Trans., 2nd series, vol. iii. p. 461.

the junction of the beds in the manner indicated in the annexed figure.

Jointed structure.—In regard to joints, they are natural fissures which often traverse rocks in straight and well-determined lines. They afford to the quarryman, as Sir R. Murchison observes, when speaking of the phenomena, as exhibited in Shropshire and the neighbouring counties, the greatest aid in the extraction of blocks of stone; and, if a sufficient number cross each other, the whole mass of rock is split into symmetrical blocks. The faces of the joints are for the most part smoother and more regular than the surfaces of true strata. The joints are straight-cut chinks, sometimes slightly open, and often passing, not only through layers of successive deposition, but also through balls of limestone or other matter, which have been formed by concretionary action since the original accumulation of the strata, and in the case of conglomerates even through quartz pebbles. Such joints, therefore, must often have resulted from one of the last changes superinduced upon sedimentary deposits.[2]

In the annexed diagram (fig. 631), the flat surfaces of rock A, B, C, represent exposed faces of joints, to which the walls of

Fig. 631.



Stratification, joints, and cleavage.
(From Murchison's 'Silurian System,' p. 245.)

other joints, J J, are parallel. S S are the lines of stratification; D D are lines of slaty cleavage, which intersect the rock at a considerable angle to the planes of stratification.

In the Swiss and Savoy Alps, as Mr. Bakewell has remarked, enormous masses of limestone are cut through so regularly by nearly vertical partings, and these joints are often so much more conspicuous than the seams of stratification, that an inexperienced observer will almost inevitably confound them, and suppose the strata to be perpendicular in places where in fact they are almost horizontal.[3]

[2] Silurian System, p. 246. [3] Introduction to Geology, chap. iv.

Now such joints are supposed to be analogous to the partings which separate volcanic and plutonic rocks into cuboidal and prismatic masses. On a small scale we see clay and starch when dry split into similar shapes; this is often caused by simple contraction, whether the shrinking be due to the evaporation of water, or to a change of temperature. It is well known that many sandstones and other rocks expand by the application of moderate degrees of heat, and then contract again on cooling; and there can be no doubt that large portions of the earth's crust have, in the course of past ages, been subjected again and again to very different degrees of heat and cold. These alternations of temperature have probably contributed largely to the production of joints in rocks.

In many countries where masses of basalt rest on sandstone, the aqueous rock has for the distance of several feet from the point of junction assumed a columnar structure similar to that of the trap. In like manner some hearthstones, after exposure to the heat of a furnace without being melted, have become prismatic. Certain crystals also acquire by the application of heat a new internal arrangement, so as to break in a new direction, their external form remaining unaltered.

Crystalline theory of cleavage.—Professor Sedgwick, speaking of the planes of slaty cleavage, where they are decidedly distinct from those of sedimentary deposition, declared in the essay before alluded to, his opinion that no retreat of parts, no contraction in the dimensions of rocks in passing to a solid state, can account for the phenomenon. He accordingly referred it to crystalline or polar forces acting simultaneously, and somewhat uniformly, in given directions, on large masses having a homogeneous composition.

Sir John Herschel, in allusion to slaty cleavage, has suggested, 'that if rocks have been so heated as to allow a commencement of crystallisation,—that is to say, if they have been heated to a point at which the particles can begin to move amongst themselves, or at least on their own axes, some general law must then determine the position in which these particles will rest on cooling. Probably, that position will have some relation to the direction in which the heat escapes. Now, when all, or a majority of particles of the same nature, have a general tendency to one position, that must of course determine a cleavage-plane. Thus we see the infinitesimal crystals of fresh precipitated sulphate of barytes, and some other such bodies, arrange themselves alike in the fluid in which they float; so as, when stirred, all to glance with one light, and give the appearance of silky

filaments. Some sorts of soap, in which insoluble margarates[4] exist, exhibit the same phenomenon when mixed with water; and what occurs in our experiments on a minute scale may occur in nature on a great one.'[5]

Mechanical theory of Cleavage.—Professor Phillips has remarked that in some slaty rocks the form of the outline of fossil shells and trilobites has been much changed by distortion, which has taken place in a longitudinal, transverse, or oblique direction. This change, he adds, seems to be the result of a 'creeping movement' of the particles of the rock along the planes of cleavage, its direction being always uniform over the same tract of country, and its amount in space being sometimes measurable, and being as much as a quarter or even half an inch.[6] Mr. D. Sharpe, following up the same line of inquiry, came to the conclusion that the present distorted forms of the shells in certain British slate rocks may be accounted for by supposing that the rocks in which they are imbedded have undergone compression in a direction perpendicular to the planes of cleavage, and a corresponding expansion in the direction of the dip of the cleavage.[7]

Subsequently (1853) Mr. Sorby demonstrated the great extent to which this mechanical theory is applicable to the slate rocks of North Wales and Devonshire,[8] districts where the amount of change in dimensions can be tested and measured by comparing the different effects exerted by lateral pressure on alternating beds of finer and coarser materials. Thus, for example, in the accompanying figure (fig. 632) it will be seen that the sandy bed *d f*, which has offered greater resistance, has been sharply contorted, while the fine-grained strata, *a*, *b*, *c*, have remained comparatively unbent. The points *d* and *f* in the stratum *d f* must have been originally four times as far apart as they are now. They have been forced so much nearer to each other, partly by bending, and partly by becoming elongated in the direction of what may be called the longer axes of their contortions, and lastly, to a certain small amount, by condensation. The chief result has obviously been due to the bending; but, in proof of elongation, it will be observed that the thickness of the bed *d f* is now about four times greater in

[4] Margaric acid is an oleaginous acid, formed from different animal and vegetable fatty substances. A margarate is a compound of this acid with soda, potash, or some other base, and is so named from its pearly lustre.

[5] Letter to the author, dated Cape of Good Hope, Feb. 20, 1836.

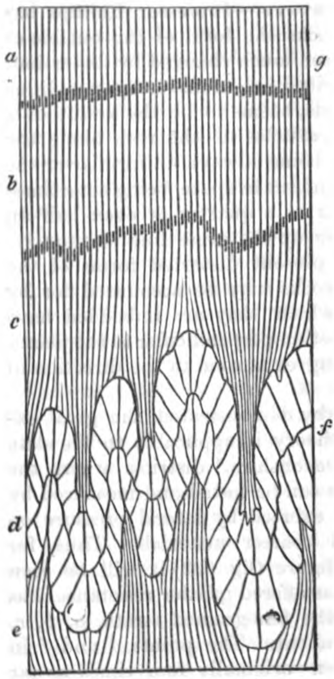
[6] Report, Brit. Assoc., Cork, 1843, Sect. p. 60.

[7] Quart. Geol. Journ., vol. iii. p. 87, 1847.

[8] On the Origin of Slaty Cleavage, by H. C. Sorby, Edinb. New. Phil. Journ. 1853, vol. lv. p. 137.

those parts lying in the main direction of the flexures than in a plane perpendicular to them; and the same bed exhibits cleavage-planes in the direction of the greatest movement, although they are much fewer than in the slaty strata above and below.

Fig. 632.



(Drawn by H. C. Sorby.)

Vertical section of slate rock in the cliffs near Ilfracombe, North Devon.

Scale one inch to one foot.

a, b, c, e. Fine-grained slates, the stratification being shown partly by lighter or darker colours, and partly by different degrees of fineness in the grain.

d, f. A coarser-grained, light-coloured sandy slate, with less perfect cleavage.

Above the sandy bed *d f*, the stratum *c* is somewhat disturbed, while the next bed *b* is much less so, and *a* not at all; yet all these beds, *c*, *b*, and *a*, must have undergone an equal amount of pressure with *d*, the points *a* and *g* having approximated as much towards each other as have *d* and *f*. The same phenomena are also repeated in the beds below *d*, and might have been shown, had the section been extended downwards. Hence it appears that the finer beds have been squeezed into a fourth of the space they previously occupied, partly by condensation, or the closer packing of their ultimate particles (which has given rise to the great specific gravity of such slates), and partly by elongation in the line of the dip of the cleavage, of which the general direction is perpendicular to that of the pressure. 'These and numerous other cases in North Devon are analogous,' says Mr. Sorby, 'to what would occur if a strip of paper were included in a mass of some soft plastic material which would readily change its dimensions. If the whole were then compressed in the direction of the length of the strip of paper, it would be bent and puckered up into contortions, whilst the plastic material would readily change its dimensions without undergoing such con-

tortions; and the difference in distance of the ends of the paper, as measured in a direct line or along it, would indicate the change in the dimensions of the plastic material.'

By microscopic examination of minute crystals, and by other observations, Mr. Sorby has come to the conclusion that the absolute condensation of the slate rocks amounts upon an average to about one half their original volume. Most of the scales of mica occurring in certain slates examined by Mr. Sorby lie in the plane of cleavage; whereas in a similar rock not exhibiting cleavage they lie with their longer axes in all directions. May not their position in the slates have been determined by the movement of elongation before alluded to? To illustrate this theory some scales of oxide of iron were mixed with soft pipe-clay in such a manner that they inclined in all directions. The dimensions of the mass were then changed artificially to a similar extent to what has occurred in slate rocks, and the pipe-clay was then dried and baked. When it was afterwards rubbed to a flat surface perpendicular to the pressure and in the line of elongation, or in a plane corresponding to that of the dip of cleavage, the particles were found to have become arranged in the same manner as in natural slates, and the mass admitted of easy fracture into thin flat pieces in the plane alluded to, whereas it would not yield in that perpendicular to the cleavage.[9]

Dr. Tyndall, when commenting in 1856 on Mr. Sorby's experiments, observed that pressure alone is sufficient to produce cleavage, and that the intervention of plates of mica or scales of oxide of iron, or any other substances having flat surfaces, is quite unnecessary. In proof of this he showed experimentally that a mass of 'pure white wax after having been submitted to great pressure, exhibited a cleavage more clean than that of any slate-rock, splitting into laminæ of surpassing tenuity.'[1] He remarks that every mass of clay or mud is divided and subdivided by surfaces among which the cohesion is comparatively small. On being subjected to pressure, such masses yield and spread out in the direction of least resistance, small nodules become converted into laminæ separated from each other by surfaces of weak cohesion, and the result is that the mass cleaves at right angles to the line in which the pressure is exerted. In further illustration of this Professor Hughes remarks that concretions which in the undisturbed beds have their longer axes parallel to the bedding are, where the rock is much cleaved, frequently found flattened laterally, so as to have their longer

[9] Sorby, as cited above, p. 741 note.

[1] Tyndall, View of the Cleavage of Crystals and Slate Rocks.

axes parallel to the cleavage planes and at a considerable angle, even right angles, to their former position.

Mr. Darwin attributes the lamination and fissile structure of volcanic rocks of the trachytic series, including some obsidians in Ascension, Mexico, and elsewhere, to their having moved when liquid in the direction of the laminæ. The zones consist sometimes of layers of air-cells drawn out and lengthened in the supposed direction of the moving mass.[2]

Foliation of Crystalline Schists.—After studying, in 1835, the crystalline rocks of South America, Mr. Darwin proposed the term *foliation* for the laminæ or plates into which gneiss, mica-schist, and other crystalline rocks are divided. Cleavage, he observes, may be applied to those divisional planes which render a rock fissile, although it may appear to the eye quite or nearly homogeneous. Foliation may be used for those alternating layers or plates of different mineralogical nature of which gneiss and other metamorphic schists are composed.

That the planes of foliation of the crystalline schists in Norway accord very generally with those of original stratification is a conclusion long since espoused by Keilhau.[3] Numerous observations made by Mr. David Forbes in the same country (the best probably in Europe for studying such phenomena on a grand scale) confirm Keilhau's opinion. In Scotland, also, Mr. D. Forbes has pointed out a striking case where the foliation is identical with the lines of stratification in rocks well seen near Crianlarich on the road to Tyndrum, about 8 miles from Inverarnan in Perthshire. There is in that locality a blue limestone foliated by the intercalation of small plates of white mica, so that the rock is often scarcely distinguishable in aspect from gneiss or mica-schist. The stratification is shown by the large beds and coloured bands of limestone all dipping, like the folia, at an angle of 32 degrees N.E.[4] In stratified formations of every age we see layers of siliceous sand with or without mica, alternating with clay, with fragments of shells or corals, or with seams of vegetable matter, and we should expect the mutual attraction of like particles to favour the crystallisation of the quartz, or mica, or felspar, or carbonate of lime along the planes of original deposition, rather than in planes placed at angles of 20 or 40 degrees to those of stratification.

After a general examination of the metamorphic rocks of the Highlands, Sir Roderick Murchison and Mr. Geikie were led to the conclusion that throughout the whole district foliation is

[2] Darwin, Volcanic Islands, pp. 69, 70.

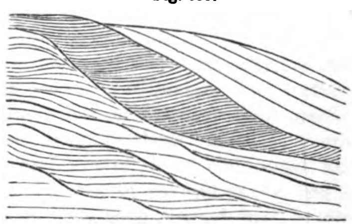
[3] Norske Mag. Naturvidsk., vol. i. p. 71.

[4] Memoir read before the Geol. Soc. London, Jan. 31, 1855.

coincident with the stratification of the rocks, and not, as had been suggested by Mr. Daniel Sharpe, with their cleavage.[5] Mr. Scrope, on the other hand, is inclined to attribute the foliation of the crystalline schists to 'the results of internal differential movements in the constituents of the subterranean mineral matter while exposed to enormous irregular pressures as well as variations of temperature, and under these influences changing at times from a solid to a fluid state and probably back again to crystalline solidity, through intervening phases of viscosity—movements and changes which must *of necessity* have frequently arranged and rearranged the component crystalline minerals, sometimes in irregular composition like that of granite, diorite, or trachyte, sometimes in laminar or schistose bands like those of gneiss, mica-schist, and other so-called metamorphic crystallines.'[6]

We have seen how much the original planes of stratification may be interfered with or even obliterated by concretionary action in deposits still retaining their fossils, as in the case of the magnesian limestone (see p. 40). Hence we must expect to be frequently baffled when we attempt to decide whether the foliation does or does not accord with that arrangement which gravitation, combined with current-action, imparted to a deposit from water. Moreover, when we look for stratification in crystalline rocks, we must be on our guard not to expect too much regularity. The occurrence of wedge-shaped masses, such as belong to coarse sand and pebbles,—diagonal lamination (p. 18), — ripple-marked,— unconformable stratification, — the fantastic folds produced by lateral pressure,—faults of various width, — intrusive dikes of trap,— organic bodies of diversified shapes,—and other causes of unevenness in the planes of deposition, both on the small and on the large scale, will interfere with parallelism. If complex and enigmatical appearances did not present themselves, it would be a serious objection to the metamorphic theory. Mr. Sorby has shown that the peculiar structure belonging to ripple-marked

Fig. 633.



Lamination of clay-stone, Montagne de Seguinat, near Gavarnie, in the Pyrenees.

[5] Quart. Geol. Journ., vol. xvii. 1861, p. 232.

[6] Scrope, 'Volcanoes,' 1872, preface, p. 18; and Geologist Mag., vol. i. p. 361.

sands, or that which is generated when ripples are formed during the deposition of the materials, is distinctly recognisable in many varieties of mica-schists in Scotland.[7]

In the preceding diagram I have represented carefully the lamination of a coarse argillaceous schist which I examined in 1830 in the Pyrenees. In part it approaches in character to a green and blue roofing-slate, while part is extremely quartzose, the whole mass passing downwards into micaceous schist. The vertical section here exhibited is about 3 feet in height, and the layers are sometimes so thin that fifty may be counted in the thickness of an inch. Some of them consist of pure quartz. There is a resemblance in such cases to the diagonal lamination which we see in sedimentary rocks, even though the layers of quartz and of mica, or of felspar and other minerals, may be more distinct in alternating folia than they were originally.

[7] H. C. Sorby, Geol. Quart. Journal, vol. xix. p. 401.

CHAPTER XXXV.

ON THE DIFFERENT AGES OF THE METAMORPHIC ROCKS.

Difficulty of ascertaining the age of metamorphic strata—Metamorphic strata of Eocene date in the Alps of Switzerland and Savoy—Limestone and shale of Carrara—Metamorphic strata of older date than the Silurian and Cambrian rocks.—Order of succession in metamorphic rocks—Uniformity of mineral character—Supposed Azoic Period—Connection between the absence of organic remains and the scarcity of calcareous matter in metamorphic rocks.

ACCORDING to the theory adopted in the last chapter, the metamorphic strata have been deposited at one period, and have become crystalline at another. We can rarely hope to define with exactness the date of both these periods, the fossils having been destroyed by plutonic action, and the mineral characters being the same, whatever the age. Superposition itself is an ambiguous test, especially when we desire to determine the period of crystallisation. Suppose, for example, we are convinced that certain metamorphic strata in the Alps, which are covered by cretaceous beds, are altered lias; this lias may have assumed its crystalline texture in the cretaceous or in some tertiary period, the Eocene for example.

When discussing the ages of the plutonic rocks, we have seen that examples occur of various primary, secondary, and tertiary deposits converted into metamorphic strata near their contact with granite. There can be no doubt in these cases that strata, once composed of mud, sand, and gravel, or of clay, marl, and shelly limestone, have for the distance of several yards, and in some instances several hundred feet, been turned into gneiss, mica-schist, hornblende-schist, chlorite-schist, quartz rock, statuary marble, and the rest. (See the two preceding chapters.) It may be easy to prove the identity of two different parts of the same stratum; one where the rock has been in contact with a volcanic or plutonic mass, and has been changed into marble or hornblende-schist, and another not far distant, where the same bed remains unaltered and fossiliferous; but when hydrothermal action, as described in the thirty-third chapter, has operated gradually on a more extensive scale, it may have finally destroyed all monuments of the date of its development

throughout a whole mountain chain, and all the labour and skill of the most practised observers are required, and may sometimes be at fault. I shall mention one or two examples of alteration on a grand scale, in order to explain to the student the kind of reasoning by which we are led to infer that dense masses of fossiliferous strata have been converted into crystalline rocks.

Eocene strata rendered metamorphic in the Alps.—In the eastern part of the Alps, some of the Palæozoic strata, as well as the older Mesozoic formations, including the oolitic and cretaceous rocks, are distinctly recognisable. Tertiary deposits also appear in a less elevated position on the flanks of the Eastern Alps; but in the Central or Swiss Alps the Palæozoic and older Mesozoic formations disappear, and the Cretaceous, Oolitic, Liassic, and at some points even the Eocene strata, graduate insensibly into metamorphic rocks, consisting of granular limestone, talc-schist, talcose-gneiss, micaceous schist, and other varieties.

As an illustration of the partial conversion into gneiss of portions of a highly inclined set of beds, I may cite Sir R. Murchison's memoir on the structure of the Alps. Slates provincially termed 'flysch' (see above, p. 261), overlying the nummulite limestone of Eocene date, and comprising some arenaceous and some calcareous layers, are seen to alternate several times with bands of granitoid rock, answering in character to gneiss. In this case heat, vapour, or water at a high temperature may have traversed the more permeable beds, and altered them so far as to admit of an internal movement and re-arrangement of the molecules, while the adjoining strata did not give passage to the same heated gases or water, or, if so, remained unchanged because they were composed of less fusible or decomposable materials. Whatever hypothesis we adopt, the phenomena establish beyond a doubt the possibility of the development of the metamorphic structure in a tertiary deposit in planes parallel to those of stratification. The strata appear clearly to have been affected, though in a less intense degree, by that same plutonic action which has entirely altered and rendered metamorphic so many of the subjacent formations; for in the Alps, this action has by no means been confined to the immediate vicinity of granite. Granite, indeed, and other plutonic rocks, rarely make their appearance at the surface, notwithstanding the deep ravines which lay open to view the internal structure of these mountains. That they exist below at no great depth we cannot doubt, for at some points, as in the Valorsine, near Mont Blanc, granite and granitic veins are observable, piercing

through talcose gneiss, which passes insensibly upwards into secondary strata.

It is certainly in the Alps of Switzerland and Savoy, more than in any other district in Europe, that the geologist is prepared to meet with the signs of an intense development of plutonic action; for here strata thousands of feet thick have been bent, folded, and overturned, and marine secondary formations of a comparatively modern date, such as the Oolitic and Cretaceous, have been upheaved to the height of 12,000, and some Eocene strata to elevations of 10,000 feet above the level of the sea; and even deposits of the Miocene era have been raised 4,000 or 5,000 feet, so as to rival in height the loftiest mountains in Great Britain. In one of the sections described by M. Studer in the highest of the Bernese Alps, namely, in the Roththal, a valley bordering the line of perpetual snow on the northern side of the Jungfrau, there occurs a mass of gneiss 1,000 feet thick, and 15,000 feet long, which I examined, not only resting upon, but also again covered by strata containing oolitic fossils. These anomalous appearances may partly be explained by supposing great solid wedges of intrusive gneiss to have been forced in laterally between strata to which I found them to be in many sections unconformable. The superposition also of the gneiss to the oolite may, in some cases, be due to a reversal of the original position of the beds in a region where the convulsions have been on so stupendous a scale.

Northern Apennines—Carrara.—The celebrated marble of Carrara, used in sculpture, was once regarded as a type of primitive limestone. It abounds in the mountains of Massa Carrara, or the 'Apuan Alps,' as they have been called, the highest peaks of which are nearly 6,000 feet high. Its great antiquity was inferred from its mineral texture, from the absence of fossils, and its passage downwards into talc-schist and garnetiferous mica-schist; these rocks again graduating downwards into gneiss, which is penetrated, at Forno, by granite veins. But the researches of MM. Savi, Boué, Pareto, Guidoni, De la Beche, Hoffmann, and Pilla demonstrated that this marble, once supposed to be formed before the existence of organic beings, is, in fact, an altered limestone of the Oolitic period, and the underlying crystalline schists are secondary or Mesozoic sandstones and shales, modified by plutonic action. In order to establish these conclusions it was first pointed out that the calcareous rocks bordering the Gulf of Spezzia, and abounding in Oolitic fossils, assume a texture like that of Carrara marble, in proportion as they are more and more invaded by certain

trappean and plutonic rocks, such as diorite, serpentine, and granite, occurring in the same country.

It was then observed that, in places where the secondary formations are unaltered, the uppermost consist of common Apennine limestone with nodules of flint, below which are shales, and at the base of all, argillaceous and siliceous sandstones. In the limestone, fossils are frequent, but very rare in the underlying shale and sandstone. Then a gradation was traced laterally from these rocks into another and corresponding series, which is completely metamorphic; for at the top of this we find a white granular marble, wholly devoid of fossils, and almost without stratification, in which there are no nodules of flint, but in its place siliceous matter disseminated through the mass in the form of prisms of quartz. Below this, and in place of the shales, are talc-schists, jasper, and hornstone; and at the bottom, instead of the siliceous and argillaceous sandstones, are quartzite and gneiss.[1] Had these secondary strata of the Apennines undergone universally as great an amount of transmutation, it would have been impossible to form a conjecture respecting their true age; and then, according to the method of classification adopted by the earlier geologists, they would have ranked as primary rocks. In that case the date of their origin would have been thrown back to an era antecedent to the deposition of all fossiliferous strata, although in reality they were formed in the Oolitic period, and altered at some subsequent and perhaps much later epoch.

Metamorphic strata of older date than the Silurian and Cambrian Rocks.—It was remarked (fig. 622, p. 567), that, as the hypogene rocks, both stratified and unstratified, crystallise originally at a certain depth beneath the surface, they must always, before they are upraised and exposed at the surface, be of considerable antiquity, relatively to a large portion of the fossiliferous and volcanic rocks. They may be forming at all periods; but before any of them can become visible, they must be raised above the level of the sea, and some of the rocks which previously concealed them must have been removed by denudation.

In Canada, as we have seen (p. 491), the Lower Laurentian gneiss, quartzite, and limestone may be regarded as metamorphic, because among other reasons organic remains (*Eozoon*

[1] See notices of Savi, Hoffmann, and others, referred to by Boué, Bull. de la Soc. Géol. de France, tom. v. p. 317; and tom. iii. p. 44; also Pilla, cited by Murchison, Quart. Geol. Journ., vol. v. p. 266.

[According to the more recent investigations of M. H. Coquand, the Carrara marble is of carboniferous age. See Geol. Mag. for July 1876, and Bull. de la Soc. Géol., 3rd series, tom. iii. p. 27 (1875).]

Canadense) have been detected in a part of one of the calcareous masses. The Upper Laurentian or Labrador series lies unconformably upon the Lower, and differs from it chiefly in having as yet yielded no fossils. It consists of gneiss with Labrador-felspar and felstones, in all 10,000 feet thick, and both its composition and structure lead us to suppose that, like the Lower Laurentian, it was originally of sedimentary origin, and owes its crystalline condition to metamorphic action. The remote date of the period when some of these old Laurentian strata of Canada were converted into gneiss, may be inferred from the fact that pebbles of that rock are found in the overlying Huronian formation, which is probably of Cambrian age (p. 489).

The oldest stratified rock of Scotland is the hornblendic gneiss of Lewis, in the Hebrides, and that of the north-west coast of Ross-shire, represented at the base of the section given at fig. 82, p. 91. It is the same as that intersected by numerous granite veins, which forms the cliffs of Cape Wrath, in Sutherlandshire (see fig. 618, p. 560), and is conjectured to be of Laurentian age. Above it, as shown in the section (fig. 82, p. 91), lie unconformable beds of a reddish or purplish sandstone and conglomerate, nearly horizontal, and between 3,000 and 4,000 feet thick. In these ancient grits no fossils have been found, but they are supposed to be of Cambrian date, for Sir R. Murchison found Lower Silurian strata resting unconformably upon them. These strata consist of quartzite with annelid burrows already alluded to (p. 91), and limestone in which Mr. Charles Peach was the first to find in 1854 three or four species of *Orthoceras*, also the genera *Cyrtoceras* and *Lituites*, two species of *Murchisonia*, a *Pleurotomaria*, a species of *Maclurea*, one of *Euomphalus*, and an *Orthis*. Several of the species are believed by Mr. Salter to be identical with Lower Silurian fossils of Canada and the United States.

The discovery of the true age of these fossiliferous rocks was one of the most important steps made of late years in the progress of British Geology, for it led to the unexpected conclusion that all the Scotch crystalline strata to the eastward, once called primitive, which overlie the limestone and quartzite in question, are referable to some part of the Silurian series.

These Scotch metamorphic strata are of gneiss, mica-schist, and clay-slate of vast thickness, and having a strike from north-east to south-west almost at right angles to that of the older Laurentian gneiss before mentioned. The newer crystalline series, comprising the crystalline rocks of Aberdeenshire, Perthshire, and Forfarshire, were inferred by Sir R. Murchison to be

altered Silurian strata, and his opinion has been since confirmed by the observations of three able geologists, Messrs. Ramsay, Harkness, and Geikie. The newest of the series is a clay-slate, on which, along the southern borders of the Grampians, the Lower Old Red, containing *Cephalaspis Lyelli*, *Pterygotus Anglicus*, and *Parka decipiens*, rests unconformably.

Order of succession in metamorphic rocks.—There is no universal and invariable order of superposition in metamorphic rocks, although a particular arrangement may prevail throughout countries of great extent, for the same reason that it is traceable in those sedimentary formations from which crystalline strata are derived. Thus, for example, we have seen that in the Apennines, near Carrara, the descending series, where it is metamorphic, consists of—1st, saccharine marble; 2ndly, talcose-schist; and 3rdly, of quartz-rock and gneiss: where unaltered, of—1st, fossiliferous limestone; 2ndly, shale; and 3rdly, sandstone.

But if we investigate different mountain chains, we find gneiss, mica-schist, hornblende-schist, chlorite-schist, hypogene limestone, and other rocks, succeeding each other, and alternating with each other in every possible order. It is, indeed, more common to meet with some variety of clay-slate forming the uppermost member of a metamorphic series than any other rock; but this fact by no means implies, as some have imagined, that all clay-slates were formed at the close of an imaginary period, when the deposition of the crystalline strata gave way to that of ordinary sedimentary deposits. Such clay-slates, in fact, are variable in composition, and sometimes alternate with fossiliferous strata, so that they may be said to belong almost equally to the sedimentary and metamorphic order of rocks. It is probable that had they been subjected to more intense plutonic action, they would have been transformed into hornblende-schist, foliated chlorite-schist, scaly talcose-schist, mica-schist, or other more perfectly crystalline rocks, such as are usually associated with gneiss.

Uniformity of mineral character in Hypogene Rocks.—It is true, as Humboldt has happily remarked, that when we pass to another hemisphere, we see new forms of animals and plants, and even new constellations in the heavens; but in the rocks we still recognise our old acquaintances—the same granite, the same gneiss, the same micaceous schist, quartz-rock, and the rest. There is certainly a great and striking general resemblance in the principal kinds of hypogene rocks in all countries, however different their ages; but each of them, as we have seen, must be regarded as geological families of rocks, and not as definite mineral compounds. They are more uniform in

aspect than sedimentary strata, because these last are often composed of fragments varying greatly in form, size, and colour, and contain fossils of different shapes and mineral composition, and acquire a variety of tints from the mixture of various kinds of sediment. The materials of such strata, if they underwent metamorphism, would be subject to chemical laws, simple and uniform in their action, the same in every climate, and wholly undisturbed by mechanical and organic causes. It would, however, be a great error to assume, as some have done, that the hypogene rocks, considered as aggregates of simple minerals, are really more homogeneous in their composition than the several members of the sedimentary series; for the proportional quantities of felspar, quartz, mica, hornblende, and other minerals, vary considerably in hypogene rocks bearing the same name.

Supposed Azoic Period.—The total absence of any trace of fossils has inclined many geologists to attribute the origin of the most ancient strata to an azoic period or one antecedent to the existence of organic beings. Admitting, they say, the obliteration, in some cases, of fossils by plutonic action, we might still expect that traces of them would oftener be found in certain ancient systems of slate which can scarcely be said to have assumed a crystalline structure. But in urging this argument, it seems to have been forgotten that there are stratified formations of enormous thickness, and of various ages, some of them even of Tertiary date, which we know were formed after the earth had become the abode of living creatures, and are, nevertheless, in some districts, entirely destitute of all vestiges of organic bodies. In some, the traces of fossils may have been effaced by water and acids, at many successive periods; indeed, the removal of the calcareous matter of fossil shells is proved by the fact of such organic remains being often replaced by silex or other minerals, and sometimes by the space once occupied by the fossil being left empty or only marked by a faint impression.

In support of this view the fact must be remembered that limestones and clays of Lias age and crowded with fossils, especially the *Gryphæa arcuata*, are found in the Hebrides graduating into rocks which are so altered that not the faintest traces of the organic structures can be detected in them. And again, while a bed of Metamorphic Lower Silurian limestone in Durness has yielded (see above, p. 603) to the patient search of Mr. Charles Peach at one favourable locality, a number of beautiful fossils, exposed upon the weathered surfaces of the rock, yet the most careful examination of similar beds of limestone upon the same geological horizon which has been made by

different observers at many other points has not in any single instance been rewarded by similar discoveries.

Those who believed the hypogene rocks to have originated antecedently to the creation of organic beings, imputed the absence of lime so remarkable in metamorphic strata to the non-existence of those mollusca and zoophytes by which shells and corals are secreted ; but when we ascribe the crystalline formations to plutonic action, it is natural to inquire whether this action itself may not tend to expel carbonic acid and lime from the materials which it reduces to fusion or semi-fusion. Not only carbonate of lime, but also free carbonic acid gas is given off plentifully from the soil and crevices of rocks in regions of active and spent volcanos, as near Naples and in Auvergne. By this process, fossil shells or corals may often lose their carbonic acid, and the residual lime may enter into the composition of augite, hornblende, garnet, and other hypogene minerals. Although we cannot descend into the subterranean regions where volcanic heat is developed, we can observe in regions of extinct volcanos, such as Auvergne and Tuscany, hundreds of springs, both cold and thermal, flowing out from granite and other rocks, and having their waters plentifully charged with carbonate of lime.

If all the calcareous matter transferred in the course of ages by these and thousands of other springs from the lower part of the earth's crust to the atmosphere, could be presented to us in a solid form, we should find that its volume was comparable to that of many a chain of hills. Calcareous matter is poured into lakes and the ocean by a thousand springs and rivers ; so that part of almost every new calcareous rock chemically precipitated, and of many reefs of shelly and coralline stone, must be derived from mineral matter subtracted by plutonic agency, and driven up by gas and steam from fused and heated rocks in the bowels of the earth.

The scarcity of limestone in many extensive regions of metamorphic rocks, as in the Eastern and Southern Grampians of Scotland, may have been the result of some action of this kind ; and if the limestones of the Lower Laurentian in Canada afford a remarkable exception to the general rule, we must not forget that it is precisely in this most ancient formation that the *Eozoon Canadense* has been found. The fact that some distinct bands of limestone from 700 to 1,500 feet thick occur here, may be connected with the escape from destruction of some few traces of organic life, even in a rock in which metamorphic action has gone so far as to produce serpentine, augite, and other minerals found largely intermixed with the carbonate of lime.

CHAPTER XXXVI.

MINERAL VEINS.

Different kinds of mineral veins—Ordinary metalliferous veins or lodes—Their frequent coincidence with faults—Proofs that they originated in fissures in solid rock—Veins shifting other veins—Polishing of their walls or 'slicken-sides'—Shells and pebbles in lodes—Evidence of the successive enlargement and reopening of veins—Examples in Cornwall and in Auvergne—Dimensions of veins—Why some alternately swell out and contract—Filling of lodes by sublimation from below—Supposed relative age of the precious metals—Copper and lead veins in Ireland older than Cornish tin—Lead vein in lias, Glamorganshire—Gold in Russia, California, and Australia—Origin of mineral veins.

THE manner in which metallic substances are distributed through the earth's crust, and more especially the phenomena of those more or less connected masses of ore called mineral veins, from which the larger part of the precious and other metals used by man is obtained, are subjects of the highest practical importance to the miner, and of no less theoretical interest to the geologist.

On different kinds of mineral veins.—The mineral veins with which we are most familiarly acquainted, are those of quartz and carbonate of lime, which are often observed to form lenticular masses of limited extent traversing both hypogene strata and fossiliferous rocks. Such veins appear to have once been chinks or small cavities, caused, like cracks in clay, by the shrinking of the mass, during desiccation, or in passing from a higher to a lower temperature. Siliceous, calcareous, and occasionally metallic matters have sometimes found their way simultaneously into such empty spaces, by infiltration from the surrounding rocks. Mixed with hot water and steam, metallic ores may have permeated the mass until they reached those receptacles formed by shrinkage, and thus gave rise to that irregular assemblage of veins, called by the Germans a 'stockwerk,' in allusion to the different floors on which the mining operations are in such cases carried on.

The more ordinary or regular veins are usually worked in vertical shafts, and have evidently been fissures produced by mechanical violence. They traverse all kinds of rocks, both hypogene and fossiliferous, and extend downwards to indefinite or unknown depths. We may assume that they correspond

with such rents as we see caused from time to time by the shock of an earthquake. Metalliferous veins, referable to such agency, are occasionally a few inches wide, but more commonly 3 or 4 feet. They hold their course continuously in a certain prevailing direction for miles or leagues, passing through rocks varying in mineral composition.

That metalliferous veins were fissures.—As some intelligent miners, after an attentive study of metalliferous veins, have been unable to reconcile many of their characteristics with the hypothesis of fissures, I shall begin by stating the evidence in its favour. The most striking fact perhaps which can be adduced in its support is, the coincidence of a considerable proportion of mineral veins with *faults*, or those dislocations of rocks which are indisputably due to mechanical force, as above explained (p. 65). There are even proofs in almost every mining district of a succession of faults, by which the opposite walls of rents, now the receptacles of metallic substances, have suffered displacement. Thus, for example, suppose *a a*, fig. 634, p. 609, to be a tin lode in Cornwall, the term *lode* being applied to veins containing metallic ores. This lode, running east and west, is a yard wide, and is shifted by a copper lode (*b b*), of similar width. The first fissure (*a a*) has been filled with various materials, partly of chemical origin, such as quartz, fluor-spar, tinstone, copper-glance, arsenical pyrites, native bismuth, and nickeliferous pyrites, and partly of mechanical origin, comprising clay and angular fragments or detritus of the intersected rocks. The successive deposits of spars and ores are, in some places, parallel to the vertical sides or walls of the vein, being divided from each other by alternating layers of clay, or other earthy matter. Occasionally, however, the metallic ores are disseminated in detached masses among the sparry minerals or vein-stones.

It is clear that, after the gradual introduction of the tinstone and other substances, the second rent (*b b*) was produced by another fracture accompanied by a displacement of the rocks along the plane of *b b*. This new opening was then filled with minerals, some of them resembling those in *a a*, as fluor-spar and quartz; others different, the copper ore being plentiful, and the tin ore wanting or very scarce. We must next suppose a third movement to occur, breaking asunder all the rocks along the line *c c*, fig. 635; the fissure, in this instance, being only 6 inches wide, and simply filled with clay, derived, probably, from the friction of the walls of the rent, or partly, perhaps, washed in from above. This new movement has displaced the rock in such a manner as to interrupt the continuity of the

copper vein (*b b*), and, at the same time, to shift or heave laterally in the same direction a portion of the tin vein which had not previously been broken.

Fig. 634.

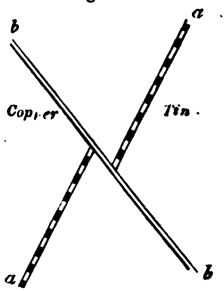


Fig. 635.

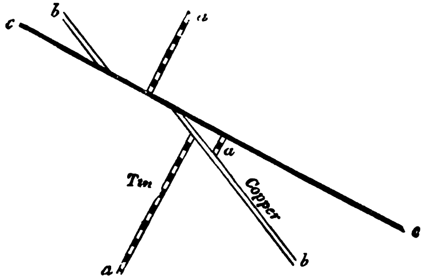
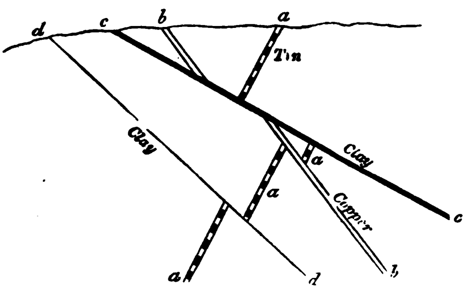


Fig. 636.



Vertical sections of the mine of Huel Peever, Redruth, Cornwall.

Again, in fig. 636 we see evidence of a fourth fissure (*d d*), also filled with clay, which has cut through the tin vein (*a a*), and has lifted it slightly upwards towards the south. The

various changes here represented are not ideal, but are exhibited in a section obtained in working an old Cornish mine, long since abandoned, in the parish of Redruth, called Huel Peever, and described both by Mr. Williams and Mr. Carne.[1] The principal movement here referred to, or that of *c c*, fig. 636, extends through a space of no less than 84 feet; but in this, as in the case of the other three, it will be seen that the outline of the country above, *d*, *c*, *b*, *a*, &c., or the geographical features of Cornwall, are not affected by any of the dislocations, a powerful denuding force having clearly been exerted subsequently to all the faults. (See above, p. 70.) It is commonly said in Cornwall, that there are eight distinct systems of veins, which can in like manner be referred to as many successive movements or fractures; and the German miners of the Hartz Mountains speak also of eight systems of veins, referable to as many periods.

Besides the proofs of mechanical action already explained, the opposite walls of veins are often beautifully polished, as if glazed, and are not unfrequently striated or scored with parallel furrows and ridges, such as would be produced by the continued rubbing together of surfaces of unequal hardness. These smoothed surfaces resemble the rocky floor over which a glacier has passed (see p. 148). They are common even in cases where there has been no shift, and occur equally in non-metalliferous fissures. They are called by miners 'slicken-sides,' from the German *schlichten*, to plane, and *seite*, side. It is supposed that the lines of the striæ indicate the direction in which the rocks were moved.

In some of the veins in the mountain limestone of Derbyshire, containing lead, the vein-stuff, which is nearly compact, is occasionally traversed by what may be called a vertical crack passing down the middle of the vein. The two faces in contact are slicken-sides, well polished and fluted, and sometimes covered by a thin coating of lead-ore. When one side of the vein-stuff is removed, the other side cracks, especially if small holes be made in it, and fragments fly off with loud explosions, and continue to do so for some days. The miner, availing himself of this circumstance, makes with his pick small holes about 6 inches apart and 4 inches deep, and on his return in a few hours finds every part ready broken to his hand.[2]

That a great many veins communicated originally with the surface of the country above, or with the bed of the sea, is

[1] Geol. Trans., vol. iv. p. 139; Trans. Royal Geol. Soc., Cornwall, vol. ii. p. 90.

[2] Conyb. and Phil. Geol., p. 401; and Farey's Derbyshire, p. 243.

proved by the occurrence in them of well-rounded pebbles, agreeing with those in superficial alluviums, as in Auvergne and Saxony. Marine fossil shells also have been found at great depths, having probably been engulphed during submarine earthquakes. Thus, a gryphæa is stated by M. Virlet to have been met with in a lead mine near Sémur, in France, and a madrepore in a compact vein of cinnabar in Hungary.[3] Mr. C. Moore has described lead-veins traversing the carboniferous limestone of the south-west of England, which at the time they were filled must have certainly been in communication with the Liassic sea, for in them have been found at great depths characteristic Lias fossils.[4] In Bohemia, similar pebbles have been met with at the depth of 180 fathoms, and in Cornwall, Mr. Carne mentions true pebbles of quartz and slate in a tin lode of the Relistran Mine, at the depth of 600 feet below the surface. They were cemented by tinstone and copper pyrites, and were traced over a space more than 12 feet long and as many wide.[5] When different sets or systems of veins occur in the same country, those which are supposed to be of contemporaneous origin, and which are filled with the same kind of metals, often maintain a general parallelism of direction. Thus, for example, both the tin and copper veins in Cornwall run nearly east and west, while the lead-veins run north and south; but there is no general law of direction common to different mining districts. The parallelism of the veins is another reason for regarding them as ordinary fissures, for we observe that faults and trap dikes, admitted by all to be masses of melted matter which have filled rents, are often parallel.

Fracture, reopening, and successive formation of veins.—Assuming, then, that veins are simply fissures in which chemical and mechanical deposits have accumulated, we may next consider the proofs of their having been filled gradually and often during successive enlargements.

Werner observed, in a vein near Gersdorff, in Saxony, no less than thirteen beds of different minerals, arranged with the utmost regularity on each side of the central layer. This layer was formed of two plates of calcareous spar, which had evidently lined the opposite walls of a vertical cavity. The thirteen beds followed each other in corresponding order, consisting of fluor-spar, heavy spar, galena, &c. In these cases the central mass has been last formed, and the two plates which coat the walls of the rent on each side are the oldest of all. If they consist of

[3] Fournet, Études sur les Dépôts Métallifères.

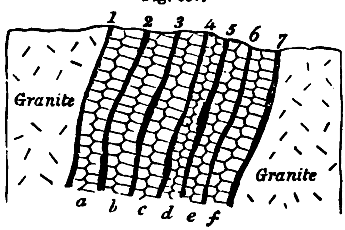
[4] Quart. Geol. Journ., vol. xxiii. (1867), p. 449.

[5] Carne, Trans. of Geol. Soc. Cornwall, vol. iii. p. 238

crystalline precipitates, they may be explained by supposing the fissure to have remained unaltered in its dimensions, while a series of changes occurred in the nature of the solutions which rose up from below: but such a mode of deposition, in the case of many successive and parallel layers, appears to be exceptional.

If a veinstone consist of crystalline matter, the points of the crystals are always turned inwards, or towards the centre of the vein; in other words, they point in the direction where there was space for the development of the crystals. Thus each new layer receives the impression of the crystals of the preceding layer, and imprints its crystals on the one which follows, until at length the whole of the vein is filled: the two layers which meet dovetail the points of their crystals the one into the other. But in Cornwall, some lodes occur where the vertical plates, or *combs*, as they are there called, exhibit crystals so dovetailed as to prove that the same fissure has been often enlarged. Sir H. De la Beche gives the following curious and instructive example (fig. 637), from a copper-mine in granite, near Redruth.[6]

Fig. 637.



Copper lode, near Redruth, enlarged at six successive periods.

Each of the plates or combs (*a*, *b*, *c*, *d*, *e*, *f*) is double, having the points of their crystals turned inwards along the axis of the comb. The sides or walls (2, 3, 4, 5, and 6) are parted by a thin covering of ochreous clay, so that each comb is readily separable from another by a moderate blow of the hammer. The breadth of each represents the whole width of the fissure at six successive periods, and the outer walls of the vein, where the first narrow rent was formed, consisted of the granitic surfaces 1 and 7.

A somewhat analogous interpretation is applicable to many other cases, where clay, sand, or angular detritus alternate with ores and veinstones. Thus, we may imagine the sides of a fissure to be encrusted with siliceous matter as Von Buch observed, in Lancerote, the walls of a volcanic crater formed in 1731 to be traversed by an open rent in which hot vapours had deposited hydrous silica, the incrustation nearly extending to the middle.[7] Such a vein may then be filled with clay or sand, and afterwards reopened, the new rent dividing the

[6] Geol. Rep. on Cornwall, p. 340.
[7] Principles, *Index*, 'Lancerote.'

argillaceous deposit, and allowing a quantity of rubbish to fall down. Various ores and spars may then be precipitated from aqueous solutions among the interstices of this heterogeneous mass.

That such changes have repeatedly occurred is demonstrated by occasional cross-veins, implying the oblique fracture of previously formed chemical and mechanical deposits. Thus, for example, M. Fournet, in his description of some mines in Auvergne worked under his superintendence, observes that the granite of that country was first penetrated by veins of massive granite, and then dislocated, so that open rents crossed both the granite and the granitic veins. Into such openings, quartz, accompanied by iron pyrites and arsenical pyrites, was introduced. Another convulsion then burst open the rocks along the old line of fracture, and the first set of deposits was cracked and often shattered, so that the new rent was filled, not only with angular fragments of the adjoining rocks, but with pieces of the older veinstones. Polished and striated surfaces on the sides or in the contents of the vein also attest the reality of these movements. A new period of repose then ensued, during which various sulphides were introduced, together with quartz of the variety known as horn-stone, by which angular fragments of the older quartz before mentioned were cemented into a breccia. This period was followed by other dilatations of the same veins, and the introduction of other sets of mineral deposits, as well as of pebbles of the basaltic lavas of Auvergne, derived from superficial alluviums, probably of Miocene or even older Pliocene date. Such repeated enlargement and reopening of veins might have been anticipated, if we adopt the theory of fissures, and reflect how few of them have ever been sealed up entirely, and that a country with fissures only partially filled must naturally offer much feebler resistance along the old lines of fracture than anywhere else.

Cause of alternate contraction and swelling of veins.—A large proportion of metalliferous veins have their opposite walls nearly parallel, and sometimes over a wide extent of country. There is a fine example of this in the celebrated vein of Andreasburg, in the Hartz, which has been worked for a depth of 500 yards perpendicularly, and 200 horizontally, retaining almost everywhere a width of 3 feet. But many lodes in Cornwall and elsewhere are extremely variable in size, being 1 or 2 inches in one part, and then 8 or 10 feet in another, at the distance of a few fathoms, and then again narrowing as before. Such alternate swelling and contraction is so often characteristic as to require explanation. The walls of fissures in general, observes Sir

H. De la Beche, are rarely perfect planes throughout their entire course, nor could we well expect them to be so, since they commonly pass through rocks of unequal hardness and different mineral composition. If, therefore, the opposite sides of such irregular fissures slide upon each other, that is to say, if there be a fault, as in the case of so many mineral veins, the parallelism of the opposite walls is at once entirely destroyed, as will be readily seen by studying the annexed diagrams.

Let *a b*, fig. 638, be a line of fracture traversing a rock, and

Fig. 638.

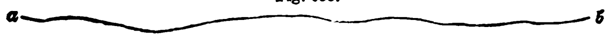


Fig. 639.

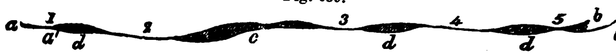
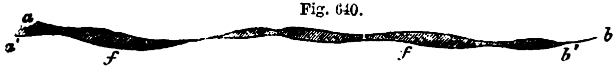
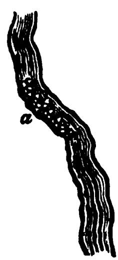


Fig. 640.



let *a b*, fig. 639, represent the same line. Now, if we cut in two a piece of paper representing this line, and then move the lower portion of this cut paper sideways from *a* to *a′*, taking care that the two pieces of paper still touch each other at the points 1, 2, 3, 4, 5, we obtain an irregular aperture at *c*, and isolated cavities *d d d*, and when we compare such figures with nature we find that, with certain modifications, they represent the interior of faults and mineral veins. If, instead of sliding the cut paper to the right hand, we move the lower part towards the left, about the same distance that it was previously slid to the right, we obtain considerable variation in the cavities so produced, two long irregular open spaces, *f f*, fig. 640, being then formed. This will serve to show to what slight circumstances considerable variations in the character of the openings between unevenly fractured surfaces may be due, such surfaces being moved upon each other, so as to have numerous points of contact.

Fig. 641.



Most lodes are perpendicular to the horizon, or nearly so; but some of them have a considerable inclination or 'hade,' as it is termed, the angles of dip being very various. The course of a vein is frequently very straight; but if tortuous, it is found to be choked up with clay, stones, and pebbles, at points where it departs most widely from verticality. Hence at places, such as *a*, fig. 641, the miner complains that the

ores are 'nipped,' or greatly reduced in quantity, the space for their free deposition having been interfered with in consequence of the preoccupancy of the lode by earthy materials. When lodes are many fathoms wide, they are usually filled for the most part with earthy matter, and fragments of rock, through which the ores are disseminated. The metallic substances frequently coat or encircle detached pieces of rock, which our miners call 'horses' or 'riders.' That we should find some mineral veins which split into branches is also natural, for we observe the same in regard to open fissures.

Chemical deposits in veins.—If we now turn from the mechanical to the chemical agencies which have been instrumental in the production of mineral veins, it may be remarked that those parts of fissures which were choked up with the ruins of fractured rocks must always have been filled with water; and almost every vein has probably been the channel by which hot springs, so common in countries of volcanos and earthquakes, have made their way to the surface. For we know that the rents in which ores abound extend downwards to vast depths, where the temperature of the interior of the earth is more elevated. We also know that mineral veins are most metalliferous near the contact of plutonic and stratified formations, especially where the former send veins into the latter, a circumstance which indicates an original proximity of veins at their inferior extremity to igneous and heated rocks. It is, moreover, acknowledged that even those mineral and thermal springs which, in the present state of the globe, are far from volcanos, are nevertheless observed to burst out along great lines of upheaval and dislocation of rocks.[8] It is also ascertained that, among the substances with which hot springs are impregnated, such as are volatile also occur in the gaseous emanations of volcanos. The whole of these are also among the constituents of the minerals most usually found in veins, such as quartz, calcspar, fluor-spar, the metallic sulphides, heavy-spar, brown-spar, and the oxides of iron. I may add that, if veins have been filled with gaseous emanations from masses of melted matter, slowly cooling in the subterranean regions, the contraction of such masses as they pass from a plastic to a solid state would, according to the experiments of Deville on granite (a rock which may be taken as a standard), produce a reduction in volume amounting to 10 per cent. The slow crystallisation, therefore, of such plutonic rocks supplies us with a force not only capable of rending open the incumbent rocks by causing a failure of support, but also of giving rise to faults whenever one portion of

[8] See Dr. Daubeny's Volcanos.

the earth's crust subsides slowly while another contiguous to it happens to rest on a different foundation, so as to remain unmoved.

Although we are led to infer, from the foregoing reasoning, that there has often been an intimate connection between metalliferous veins and hot springs holding mineral matter in solution, yet we must not on that account expect that the contents of hot springs and mineral veins would be identical. On the contrary, M. E. de Beaumont has judiciously observed that we ought to find in veins those substances which, being least soluble, are not discharged by hot springs,—or that class of simple and compound bodies which the thermal waters ascending from below would first precipitate on the walls of a fissure, as soon as their temperature began slightly to diminish. The higher they mount towards the surface, the more will they cool till they acquire the average temperature of springs, being in that case chiefly charged with the most soluble substances, such as the alkalis, soda and potash. These are seldom met with in veins, although they enter so largely into the composition of granitic rocks.[9]

To a certain extent, therefore, the arrangement and distribution of metallic matter in veins may be referred to ordinary chemical action, or to those variations in temperature which waters holding the ores in solution must undergo as they rise upwards from great depths in the earth. But there are other phenomena which do not admit of the same simple explanation. Thus, for example, in Derbyshire, veins containing ores of lead, zinc, and copper, but chiefly lead, traverse alternate beds of limestone and basalt. The ore is plentiful where the walls of the rent consist of limestone, but is reduced to a mere string when they are formed of basalt, or 'toad-stone,' as it is called provincially. Not that the original fissure is narrower where the basalt occurs, but because more of the space is there filled with veinstones, and the waters at such points have not parted so freely with their metallic contents.

'Lodes in Cornwall,' says Mr. Robert W. Fox, 'are very much influenced in their metallic riches by the nature of the rock which they traverse, and they often change in this respect very suddenly, in passing from one rock to another. Thus many lodes which yield abundance of ore in granite, are unproductive in clay-slate, or killas, and *vice versâ.*'

Supposed relative age of the different metals.—After duly reflecting on the facts above described, we cannot doubt that

[9] Bulletin, iv. p. 1278.

mineral veins, like eruptions of granite or trap, are referable to many distinct periods of the earth's history, although it may be more difficult to determine the precise age of veins; because they have often remained open for ages, and because, as we have seen, the same fissure, after having been once filled, has frequently been reopened or enlarged. But besides this diversity of age, it has been supposed by some geologists that certain metals have been produced exclusively in earlier, others in more modern times,—that tin, for example, is of higher antiquity than copper, copper than lead or silver, and all of them more ancient than gold. I shall first point out that the facts once relied upon in support of some of these views are contradicted by later experience, and then consider how far any chronological order of arrangement can be recognised in the position of the precious and other metals in the earth's crust.

In the first place, it is not true that veins in which tin abounds are the oldest lodes worked in Great Britain. The Government survey of Ireland has demonstrated that in Wexford, veins of copper and lead (the latter as usual being argentiferous) are much older than the tin of Cornwall. In each of the two countries a very similar series of geological changes has occurred at two distinct epochs,—in Wexford, before the Devonian strata were deposited; in Cornwall, after the carboniferous epoch. To begin with the Irish mining district: We have granite in Wexford, traversed by granite veins, which veins also intrude themselves into the Silurian strata, the same Silurian rocks as well as the veins having been denuded before the Devonian beds were superimposed. Next we find, in the same county, that elvans, or straight dikes of porphyritic felsite, have cut through the granite and the veins before mentioned, but have not penetrated the Devonian rocks. Subsequently to these elvans, veins of copper and lead were produced, being of a date certainly posterior to the Silurian, and anterior to the Devonian; for they do not enter the latter, and what is still more decisive, streaks or layers of derivative copper have been found near Wexford in the Devonian, not far from points where mines of copper are worked in the Silurian strata.

Although the precise age of such copper lodes cannot be defined, we may safely affirm that they were either filled at the close of the Silurian or commencement of the Devonian period. Besides copper, lead, and silver, there is some gold in these ancient or primary metalliferous veins. A few fragments also of tin found in Wicklow in the drift are supposed to have been derived from veins of the same age.[1]

[1] Sir H. De la Beche, MS. Notes on Irish Survey.

Next, if we turn to Cornwall, we find there also the monuments of a very analogous sequence of events. First the granite was formed; then, about the same period, veins of fine-grained granite, often tortuous (see fig. 618, p. 560), penetrating both the outer crust of granite and the adjoining Paleozoic fossiliferous rocks, including the coal-measures; thirdly, elvans, holding their course straight through granite, granitic veins, and fossiliferous slates; fourthly, veins of tin also containing copper, the first of those eight systems of fissures of different ages already alluded to, p. 610. Here, then, the tin lodes are newer than the elvans. It has indeed been stated by some Cornish miners that the elvans are in some instances posterior to the oldest tin-bearing lodes, but the observations of Sir H. De la Beche during the survey led him to an opposite conclusion, and he has shown how the cases referred to in corroboration can be otherwise interpreted.[2] We may, therefore, assert that the most ancient Cornish lodes are younger than the coal-measures of that part of England, and it follows that they are of a much later date than the Irish copper and lead of Wexford and some adjoining counties. How much later, it is not so easy to declare, although probably they are not newer than the beginning of the Permian period, as no tin lodes have been discovered in any red sandstone which overlies the coal in the south-west of England.

There are lead veins in Glamorganshire which enter the lias, and others near Frome, in Somersetshire, which have been traced into the Inferior Oolite. In Bohemia, the rich veins of silver of Joachimsthal cut through basalt containing olivine, which overlies tertiary lignite, in which are leaves of dicotyledonous trees. This silver, therefore, is decidedly a tertiary formation. In regard to the age of the gold of the Ural Mountains, in Russia, which, like that of California, is obtained chiefly from auriferous alluvium, it occurs in veins of quartz in the schistose and granitic rocks of that chain, and is supposed by Sir R. Murchison, MM. De Verneuil and Keyserling to be newer than the hornblendic granite of the Ural—perhaps of tertiary date. They observe, that no gold has yet been found in the Permian conglomerates which lie at the base of the Ural Mountains, although large quantities of iron and copper detritus are mixed with the pebbles of those Permian strata. Hence it seems that the Uralian quartz veins, containing gold and platinum, were not formed, or certainly not exposed to aqueous denudation, during the Permian era.

In the auriferous alluvium of Russia, California, and Australia, the bones of extinct land-quadrupeds have been met with,

[2] Report on Geology of Cornwall, p. 310.

those of the mammoth being common in the gravel at the foot of the Ural Mountains; while in Australia they consist of huge marsupials, some of them of the size of the rhinoceros and allied to the living wombat. They belong to the genera Diprotodon and Nototherium of Professor Owen. The gold of Northern Chili is associated in the mines of Los Hornos with copper pyrites, in veins traversing the cretaceo-jurassic formations, so called because its fossils have the character partly of the cretaceous and partly of the jurassic fauna of Europe.[3] The gold found in the United States, in the mountainous parts of Virginia, North and South Carolina, and Georgia, occurs in metamorphic Silurian strata, as well as in auriferous gravel derived from the same. In Queensland, according to the researches of Mr. Daintree, the auriferous lodes are entirely confined to those districts which are traversed by a series of trap-rocks of peculiar character.[4]

Gold has now been detected in almost every kind of rock, in slate, quartzite, sandstone, limestone, granite, and serpentine, both in veins and in the rocks themselves at short distances from the veins. In Australia it has been worked successfully not only in alluvium, but in veinstones in the native rock, generally consisting of Silurian shales and slates. It has been traced on that continent over more than nine degrees of latitude (between the parallels of 30° and 39° S.), and over twelve of longitude, and yielded in 1853 an annual supply equal, if not superior, to that of California; nor is there any apparent prospect of this supply diminishing, still less of the exhaustion of the gold-fields.

Origin of gold in California and South America.—In 1864 Professor Whitney[5] showed that the detrital gold deposits worked in California were of fluviatile origin and of two distinct ages: the more ancient or Pliocene had been protected by a cover of hard lava poured out over it from the volcanos of the higher part of the Sierra; whilst the later or Post-tertiary auriferous gravels, formed since the period of greatest volcanic activity above alluded to, contained remains of the mastodon and elephant, and belong to the epoch of man. He also announced that some of the gold veins themselves were probably of cretaceous age, as had been shown to be the case in South America by Mr. David Forbes.[6] The last-mentioned mineralogist had already in 1861 advanced the opinion that the gold veins in South America and many other countries were of two distinct ages,

[3] Darwin's S. America, p. 209, &c.

[4] Quart. Geol. Journ., vol. xxviii. 1872, p. 291.

[5] Amer. Journ. Scien., Sept. 1864.

[6] Quart. Journ. Geol. Soc., vol. xvii. 1861.

and connected with the outbursts of respectively Granitic or Dioritic rocks, the former or older being not later than the carboniferous, and the latter as recent as the cretaceous period.

Mr. J. Arthur Phillips stated his belief in 1868[7] that the formation of recent metalliferous veins is now going on in various parts of the Pacific Coast. Thus, for example, there are fissures at the foot of the eastern declivity of the Sierra Nevada in the State of that name, from which boiling water and steam escape, forming siliceous incrustations on the sides of the fissures. In one case where the fissure is partially filled up with silica enclosing iron and copper pyrites, gold is said to have been found in the veinstone. Mr. Belt, however, who has lately made a special study of auriferous quartz veins in Nicaragua, is of opinion that although since the lodes were first filled they have been subjected to various chemical and hydrothermal agencies, the veins themselves have been originally igneous injections similar to the dikes and veins of granite.

Mr. Belt has also suggested geological reasons for the richness of ore near the surface of many gold fields. One thousand ounces of gold were obtained from a small patch of ore near the surface of the Consuelo lode in Nicaragua; and at Santo Domingo and elsewhere very rich ore was discovered within a few fathoms of the surface. When, however, these deposits were followed downwards, they invariably got poorer, and at one hundred feet from the surface no very rich ore has been met with. Below that, when the works are prosecuted still deeper there does not appear to be any further progressive deterioration in the value of the ore. The cause, says Mr. Belt, of these rich deposits near the surface does not appear to him to be that the lodes originally, before they were exposed to denudation, contained more gold in their upper portions than below, but to be the effect of the gradual denudation and wearing away of the surface, causing an accumulation of the loose gold in the upper parts of the lodes, derived from parts that originally stood higher, and have now been worn away by the action of the elements. This accumulation of loose gold near the surface of auriferous veins, set at liberty from its matrix by the decomposition of the ore, and concentrated by degradation, is probably the reason of the great richness of many of what are called the caps of quartz veins, that is, the parts next the existing surface, and has also perhaps originated the belief that auriferous veins deteriorate in value with depth.[8]

It has been remarked by M. De Beaumont, that lead and

[7] Proc. Royal Soc., 1868, p. 294.

[8] Belt, Naturalist in Nicaragua, 1874, p. 90.

some other metals are found in dikes of basalt as well as in mineral veins connected with trap-rock, whereas tin is met with in granite and in veins associated with the plutonic series. If this rule hold true generally, the geological position of tin accessible to the miner will belong, for the most part, to rocks older than those bearing lead. The tin veins will be of higher relative antiquity for the same reason that the 'underlying' igneous formations or granites which are visible to man are older, on the whole, than the overlying or trappean formations. Mr. David Forbes[9] has also found in South America and elsewhere, that not only are metallic lodes intimately associated with the appearance of eruptive rocks in their vicinity, but also that their metallic contents are strongly influenced by the nature of the rock so intruded.

If different sets of fissures, originating simultaneously at different levels in the earth's crust, and communicating, some of them with volcanic, others with heated plutonic masses, be filled with different metals, it will follow that those formed farthest from the surface will usually require the longest time before they can be exposed superficially. In order to bring them into view, or within reach of the miner, a greater amount of upheaval and denudation must take place in proportion as they have lain deeper when first formed and fitted. A considerable series of geological revolutions must intervene before any part of the fissure, which has been for ages in the proximity of the plutonic rocks, so as to receive the gases discharged from it when it was cooling, can emerge into the atmosphere. But I need not enlarge on this subject, as the reader will remember what was said in the 30th, 32nd, and 35th chapters, on the chronology of the volcanic and hypogene formations.

[9] Mineralogy of South America, Phil. Mag., vol. xxix.

TABLE OF BRITISH FOSSILS.

THE following tables, which have been drawn up by Mr. Etheridge, refer, as will be seen by the title, exclusively to British fossils, and this will explain the absence of that portion of the Palæozoic series which is alluded to in Chapter XXVII. under the title of Laurentian, and in which the Eozoon found in Canada is at present the only known organism, and one not yet found in Britain.

The rise, culmination, and decrease of each Order or Family are shown by the gradual swelling out and thinning off of the black lines, while the survival of certain Orders or Families up to the present day is indicated by the reappearance of the black line in the Recent column, even when a gap in the British strata (as for example in the Miocene column) makes it appear as if such forms had died out. This method of indicating by black lines the rise and development of a fossil form was, I believe, first introduced by Bronn, adopted by Louis Agassiz, and afterwards constantly used by Edward Forbes in his geological lectures.

The table shows the range of all the chief Classes, Orders, and Families. The enumeration of Genera would occupy far too much space, although the information would have been extremely valuable.

TABLE OF BRITISH FOSSILS

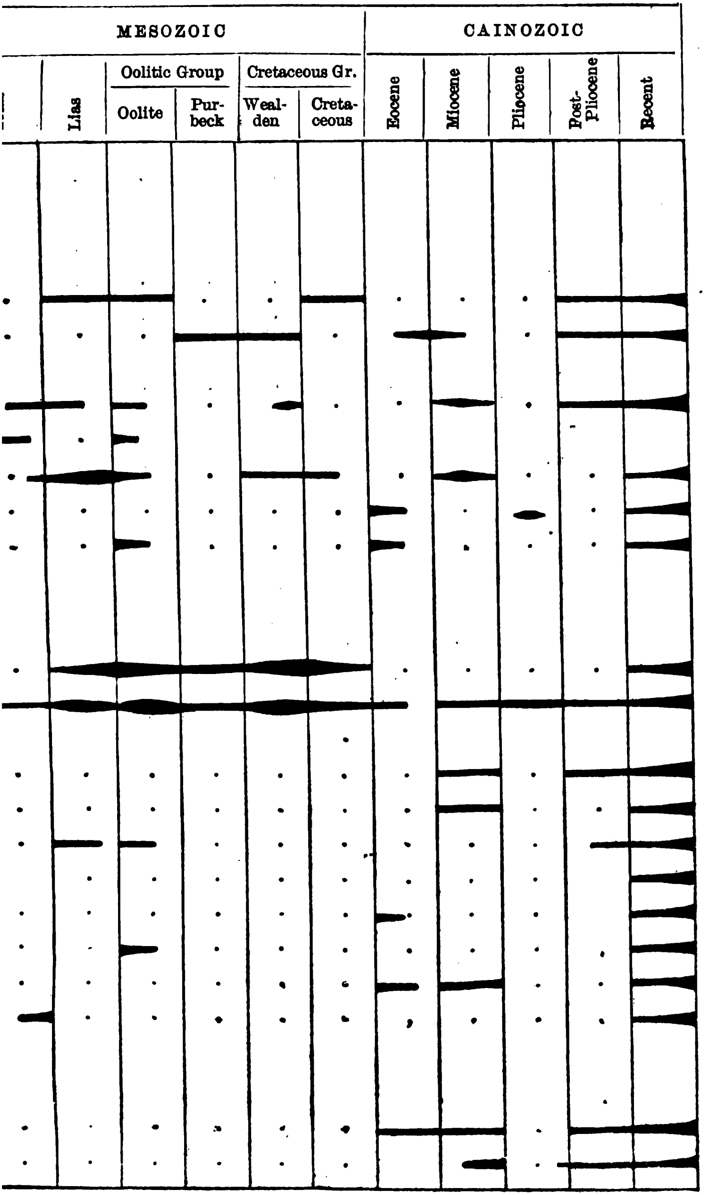
ILLUSTRATIVE OF THE SUCCESSIVE APPEARANCE

AND DEVELOPMENT IN TIME OF THE CHIEF ORDERS, CLASSES, OR

FAMILIES OF ANIMALS AND PLANTS IN BRITAIN.

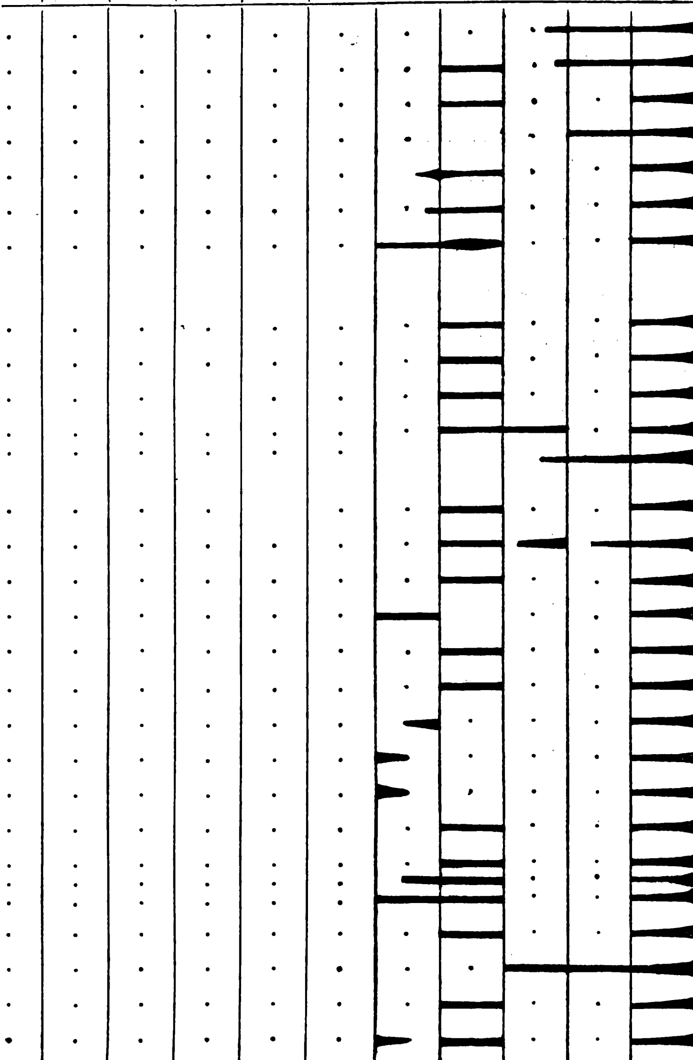
N.B.—The column headed 'Recent' indicates the survival of certain classes and families (the Marsupialia and Palms, for example) in some portion of the globe at the present day, and not exclusively in Britain.

Classes, Orders, and Families	Palæozoic: Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
Kingdom PLANTÆ.						
Class Cryptogamia.						
Cellulares.						
Fam. Algæ	.					
— Characeæ	.	.	.	.	.	.
Vasculares.						
Fam. Equisetaceæ	.	.	.	.		.
— Calamiteæ	.	.	.			
— Filices	.	.	.			
— Osmundeæ	.	.	.	.	.	.
— Lycopodiaceæ	.	.	?	.		
— Sigillariæ	.	.	.	.		
Class Phanerogamia.						
Sub-class *Gymnospermæ.*						
Fam. Cycadaceæ	.	.	.	.	.	.
— Coniferæ (many genera)	.		.			
Sub-class *Monocotyledones.*						
Fam. Cyperaceæ	.	.	.	.	.	.
— Gramineæ	.	.	.	.	.	.
— Naiadaceæ	.	.	.	.	.	.
— Pandanaceæ	.	.	.	.	.	.
— Nipaceæ	.	.	.	.	.	.
— Aroideæ	.	.	.	.	.	.
— Palmæ	.	.	.	.	.	.
— Typhaceæ	.	.	.	.	.	.
Sub-class *Dicotyledones.*						
Apetalæ.						
Fam. Ceratophyllaceæ	.	.	.	.	.	.
— Cupuliferæ	.	.	.	.	.	.

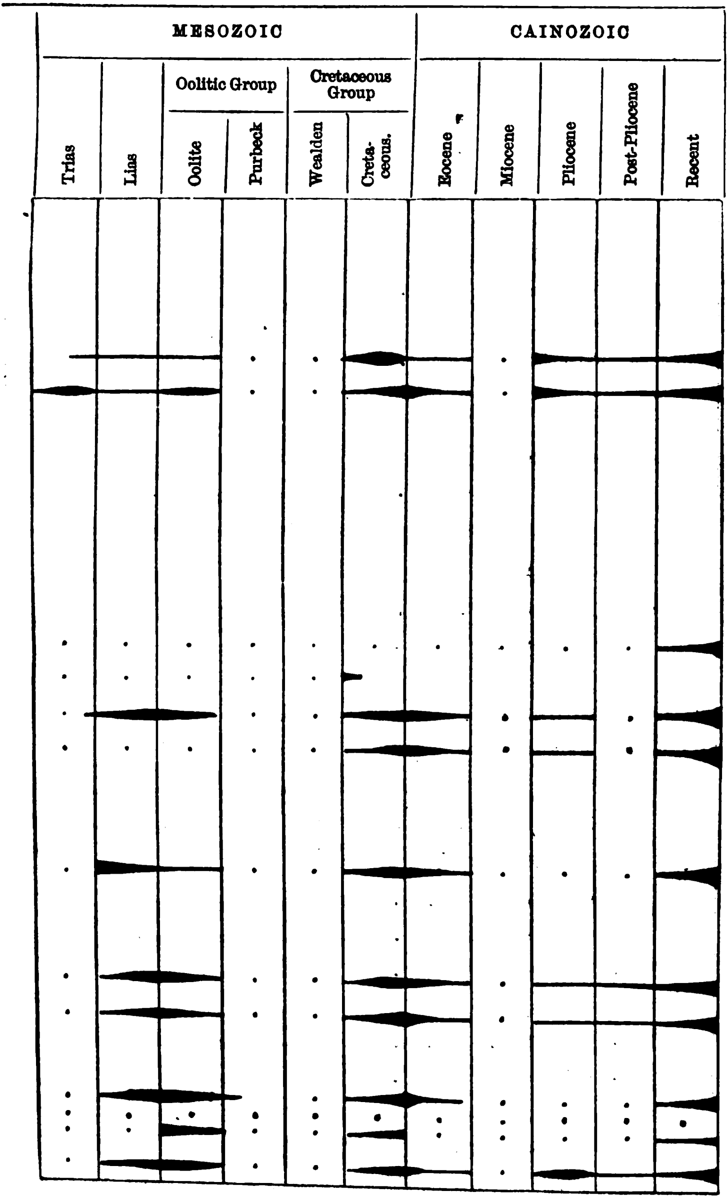

MESOZOIC
CAINOZOIC
Lias
Oolitic Group
Oolite
Pur-beck
Cretaceous Gr.
Weal-den
Creta-ceous
Eocene
Miocene
Pliocene
Post-Pliocene
Recent

Classes, Orders, and Families	Palæozoic					
	Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	[illegible]
Fam. Salicineæ	.	.	.	.	.	.
— Betulaceæ	.	.	.	.	.	.
— Platanaceæ	.	.	.	.	.	.
— Myricaceæ	.	.	.	.	.	.
— Artocarpeæ	.	.	.	.	.	.
— Lauraceæ	.	.	.	.	.	.
— Proteaceæ	.	.	.	.	.	.
Monopetalæ.						
Fam. Rubiaceæ	.	.	.	.	.	.
— Apocynaceæ	.	.	.	.	.	.
— Ericaceæ	.	.	.	.	.	.
— Vacciniaceæ	.	.	.	.	.	.
— Gentianaceæ	.	.	.	.	.	.
Polypetalæ.						
Fam. Anonaceæ	.	.	.	.	.	.
— Nymphæaceæ	.	.	.	.	.	.
— Nelumbiaceæ	.	.	.	.	.	.
— Cucurbitaceæ	.	.	.	.	.	.
— Alangiaceæ	.	.	.	.	.	.
— Myrtaceæ	.	.	.	.	.	.
— Malvaceæ	.	.	.	.	.	.
— Aurantiaceæ	.	.	.	.	.	.
— Sapindaceæ	.	.	.	.	.	.
— Vitaceæ	.	.	.	.	.	.
— Euphorbiaceæ	.	.	.	.	.	.
— Moraceæ	.	.	.	.	.	.
— Rhamnaceæ	.	.	.	.	.	.
— Juglandaceæ	.	.	.	.	.	.
— Rosaceæ	.	.	.	.	.	.
— Celastraceæ	.	.	.	.	.	.
— Leguminoseæ	.	.	.	.	.	.

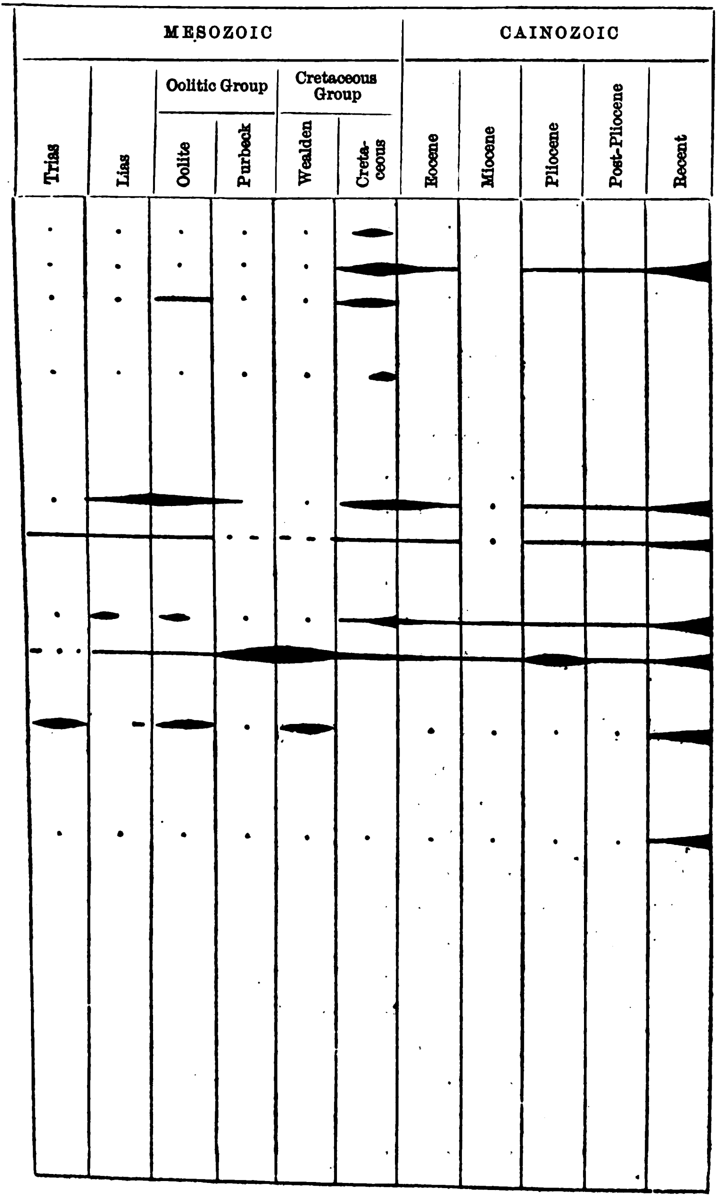
MESOZOIC						CAINOZOIC				
		Oolitic Group		Cretaceous Gr.						
Trias	Lias	Oolite	Pur-beck	Weal-den	Creta-ceous	Eocene	Miocene	Pliocene	Post Pliocene	Recent



Classes, Orders, and Families	Palæozoic: Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
INVERTEBRATA.						
Sub-Kingdom **Protozoa.**						
Class Rhizopoda.						
Order Spongida, &c.						
— Foraminifera						
Sub-Kingdom **Cœlenterata.**						
Class Hydrozoa.						
Fam. Graptolitidæ						
Class Actinozoa.						
Corallaria.						
— Tabulata						
— Rugosa						
— Aporosa						
— Perforata						
Sub-Kingdom **Annuloida.**						
Class Echinodermata.						
Order Crinoidea						
— Cystoidea						
— Blastoidea						
— Ophiuroidea						
— Asteroidea						
Fam. Palæchinidæ						
— Cidaridæ						
— Archæcidaridæ						
— Cassidulidæ						
— Echinidæ						


MESOZOIC
CAINOZOIC
Oolitic Group
Cretaceous Group
Trias
Lias
Oolite
Purbeck
Wealden
Creta-ceous.
Eocene
Miocene
Pliocene
Post-Pliocene
Recent

	Classes, Orders, and Families	PALÆOZOIC Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
	Fam. Ananchytidæ	.	.	.	.	.	.
	— Spatangidæ	.	.	.	.	.	.
	— Galeritidæ	.	.	.	.	.	.
	— Marsupitidæ	.	.	.	.	.	.
	Sub-Kingdom Annulosa.						
	Class Annelida.						
	Order Tubicola (*Serpulæ*)	—	—	—	—	—	—
	Errantia (*Arenicolæ*)	—	—	—	—	—	—
	Class Crustacea.						
	Order Cirripedia, &c.	.	.	—	.	.	.
Entomostraca	— Ostracoda		—	—	—	—	—
	— Phyllopoda	—	—	—	—	—	.
	Merostomata.						
	— Eurypterida	.	.	—	—	—	
	— Xiphosura	.	.	—	.	—	.
	Group Trilobita						
	Fam. Phacopidæ	.	—	—	—		
	— Cheiruridæ	.	—	—	—		
	— Acidaspidæ	.	—	—			
	— Cyphaspidæ	.	—				
	— Harpedidæ	.	—	—	—		
	— Calymenidæ	.	—	—	—		
	— Conocephalidæ	—	—				
	— Paradoxidæ	—					


MESOZOIC
CAINOZOIC
Oolitic Group
Cretaceous Group
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Lias
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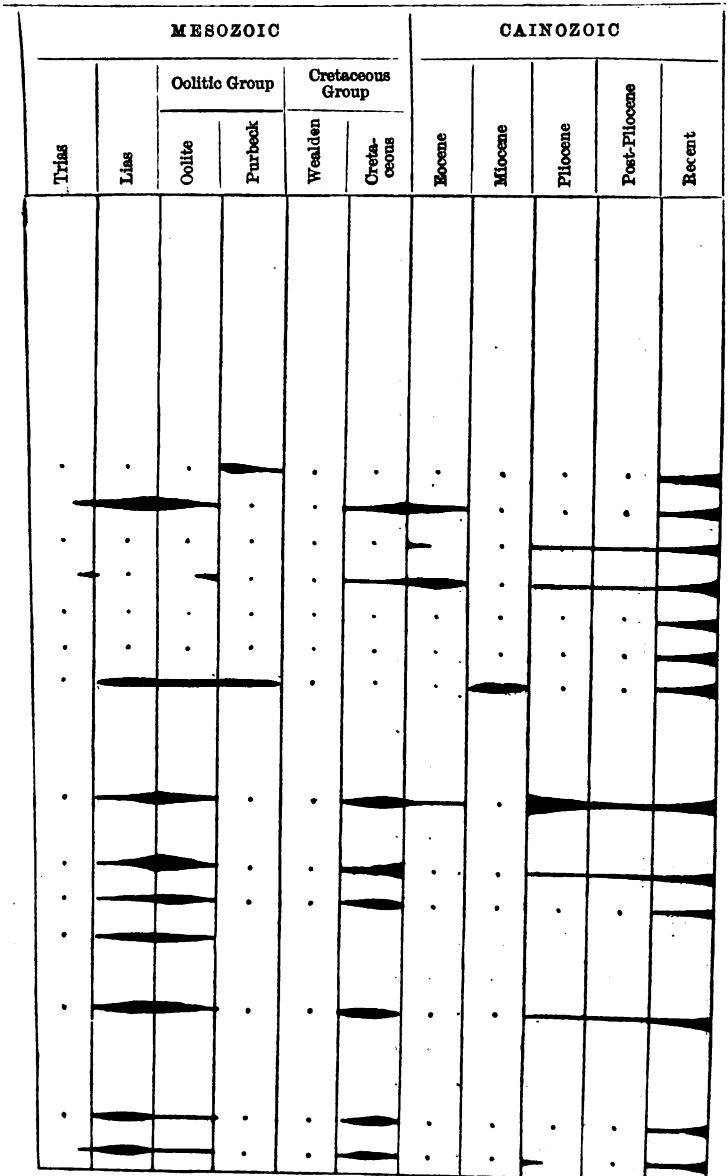
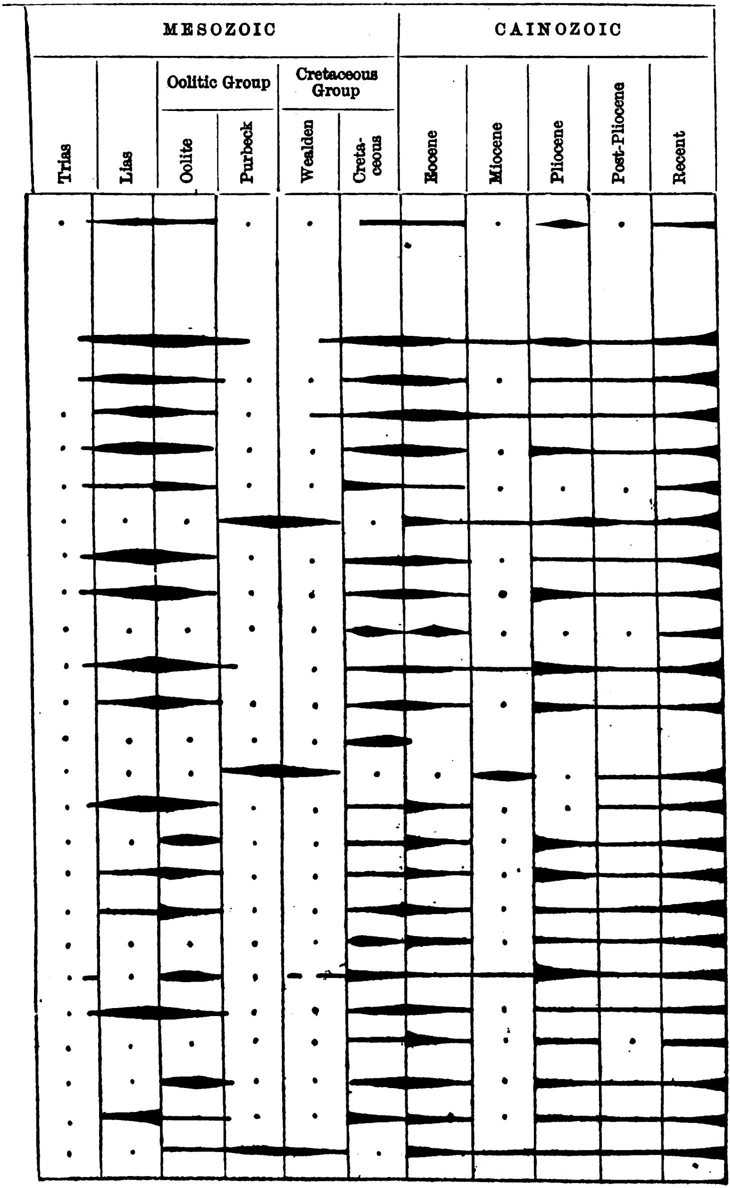
Purbeck
Wealden
Creta-ceous
Eocene
Miocene
Pliocene
Post-Pliocene
Recent

Classes, Orders, and Families	Palæozoic: Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
Entomostraca—*continued.* Fam. Olenidæ	▬	▬				
— Asaphidæ	.	▬	▬			
— Bronteidæ	.	▬	▬	▬		
— Proteideæ	.	.	▬	▬	▬	
— Trinucleidæ	.	▬	▬			
— Agnostidæ	▬	▬				
Sub-Class Malacostraca						
Order Isopoda	.	.	.	.	.	▬
— Macrura	.	.	.	.	▬	▬
— Anomura	.	.	.	.	.	.
— Brachyura	.	.	.	.	.	.
Class Arachnida	.	.	.	.	▬	.
Class Myriapoda	.	.	.	.	▬	.
Class Insecta	.	.	.	.	▬	.
Sub-Kingdom Mollusca.						
Division Molluscoida.						
Class Polyzoa	.	▬	▬	▬	▬	▬
Class Brachiopoda						
Fam. Terebratulidæ	.	.	.	▬	▬	▬
— Thecididæ	.	.	.	.	.	.
— Spiriferidæ	.	.	▬	▬	▬	▬
— Orthidæ	▬	▬	▬	▬	▬	
— Rhynchonellidæ	.	.	▬	▬	▬	▬
— Strophomenidæ	.	▬	▬	▬	▬	
— Productidæ	.	.	.	▬	▬	▬
— Craniadæ	.	▬	▬	▬	▬	▬
— Discinidæ	.	▬	▬	▬	▬	▬


MESOZOIC
CAINOZOIC
Oolitic Group
Cretaceous Group
Trias
Lias
Oolite
Purbeck
Wealden
Creta-ceous
Eocene
Miocene
Pliocene
Post-Pliocene
Recent

	Classes, Orders, and Families	Palæozoic: Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
Brachiopoda	Fam. Lingulidæ	▬	▬	▬	▬	▬	▬
	— *Calceolidæ*	.	.	.	▬		
Class Lamellibranchiata.							
Asiphonida	Fam. Ostreidæ	.	.	.	.	.	.
	— Aviculidæ	.	▬	▬	▬	▬	▬
	— Mytillidæ	.	▬	▬	▬	▬	▬
	— Arcadæ	▬	▬	▬	▬	▬	▬
	— Trigoniadæ	.	▬	▬	▬	▬	▬
	— Unionidæ	.	.	.	▬	.	.
	— Limidæ	.	.	.	.	.	.
	— Pectinidæ	.	.	.	.	.	▬
Siphonida	— Chamidæ	.	.	.	.	.	.
	— Cardiidæ	.	.	▬	▬	▬	.
	— Lucinidæ	.	.	.	.	.	.
	— Hippuritidæ	.	.	.	.	.	.
	— Cycladidæ	.	.	.	.	.	.
	— Cyprinidæ	.	.	.	▬	▬	▬
	— Veneridæ	.	.	.	▬	.	.
	— Mactridæ	.	.	.	.	.	.
	— Tellinidæ	.	.	▬	▬	▬	▬
	— Solenidæ	.	.	▬	.	▬	▬
	— Myadæ	.	.	▬	▬	▬	.
	— Anatinidæ	.	.	▬	.	▬	▬
	— Gastrochænidæ	.	.	.	.	.	.
	— Pholadidæ	.	.	.	.	▬	.
	— Nuculidæ	▬	▬	▬	▬	▬	▬
	— Cyrenidæ	.	.	.	.	.	.


MESOZOIC
CAINOZOIC
Oolitic Group
Cretaceous Group
Trias
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Purbeck
Wealden
Creta-ceous
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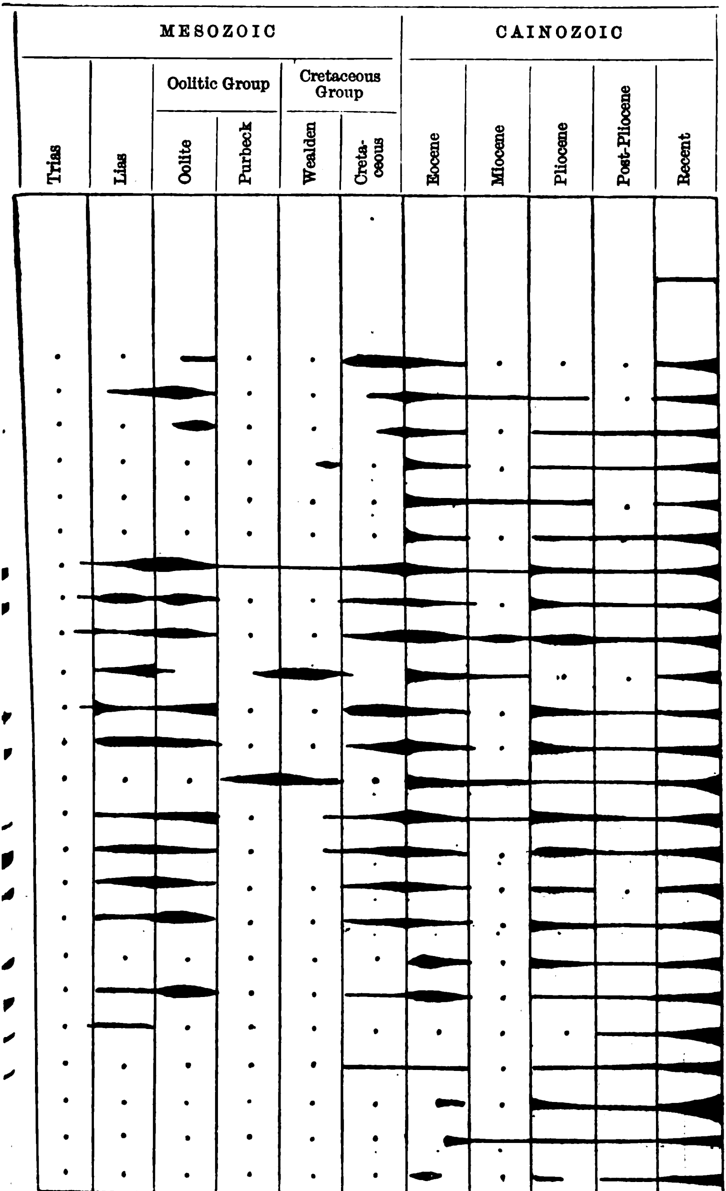
Miocene
Pliocene
Post-Pliocene
Recent

Classes, Orders, and Families	Palæozoic: Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
Nucleo-bran-chiata						
Fam. Bellerophontidæ		——	——	——	——	
— Atlantidæ	——	——	——	——	——	
Class Gasteropoda.						
Siphonostomata						
Fam. Strombidæ	.	.	.	.	.	.
— Muricidæ	.	.	.	.	.	.
— Buccinidæ	.	.	.	- -	- -	.
— Conidæ	.	.	.	.	.	.
— Volutidæ	.	.	.	.	.	.
— Cypræidæ	.	.	.	.	.	.
Holostomata						
— Naticidæ	.	.	——	——	——	——
— Pyramidellidæ	.	.	——	——	——	.
— Cerithiadæ	.	.	.	.	.	.
— Melaniadæ	.	.	.	.	.	.
— Turritelidæ	.	.	——	——	——	.
— Littorinidæ	.	.	.	.	——	——
— Paludinidæ	.	.	.	.	.	.
— Neritidæ	.	.	——	——	——	.
— Turbinidæ	.	——	——	——	——	——
— Haliotidæ	.	——	——	——	——	.
— Fissurellidæ	.	.	.	.	.	.
— Calyptreidæ	.	——	——	——	——	.
— Patellidæ	.	.	——	.	——	.
— Chitonidæ	.	.	——		——	——
— Dentaliadæ	.	.	.	.	——	——
Inopercu-lata						
— Helicidæ	.	.	.	.	.	.
— Limnæidæ	.	.	.	.	.	.
— Auriculidæ	.	.	.	.	.	.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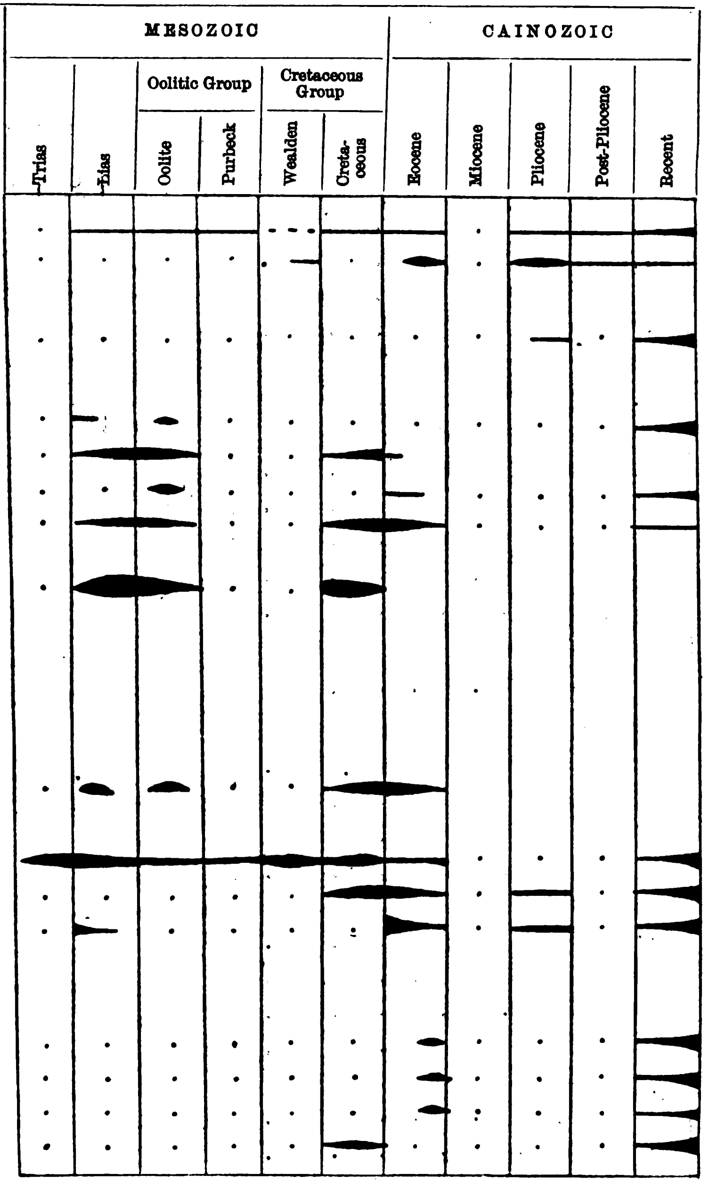
Post-Pliocene
Recent

Classes, Orders, and Families	Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
	PALÆOZOIC					
Tectibranchiata — Fam. Tornatellidæ .	.	.	.	.	.	.
Tectibranchiata — Bullidæ .	.	.	.	.	.	.
Class Pteropoda.						
Fam. Hyleidæ .	.	—	—	—	—	—
Class Cephalopoda.						
Dibranchiata — Fam. Teuthidæ	.	.	.	.	.	.
Dibranchiata — Belemnitidæ .	.	.	.	.	.	.
Dibranchiata — Sepiadæ	.	.	.	.	.	.
Tetrabranchiata — Nautilidæ .	.	—	—	—	—	—
Tetrabranchiata — Orthoceratidæ.	—	—	—	—	—	
Tetrabranchiata — Ammonitidæ .	.	.	.	.	—	.
VERTEBRATA.						
Class Pisces.						
Order Elasmobranchii.						
Sub-Order *Holocephali.*						
Fam. Edaphodontidæ .	.	.	.	.	.	.
Sub-Order *Plagiostomi.*						
Fam. Cestraphori .	.	.	.	—	—	—
— Squalidæ (Selachii)	.	.	.	.	.	.
— Raidæ .	.	.	.	.	—	.
Order Teleostei.						
Sub-Order A. *Malacopteri.*						
Fam. Siluridæ .	.	.	.	.	.	.
— Cyprinidæ	.	.	.	.	.	.
— Characini .	.	.	.	.	.	.
— Salmonidæ	.	.	.	.	.	.


MESOZOIC
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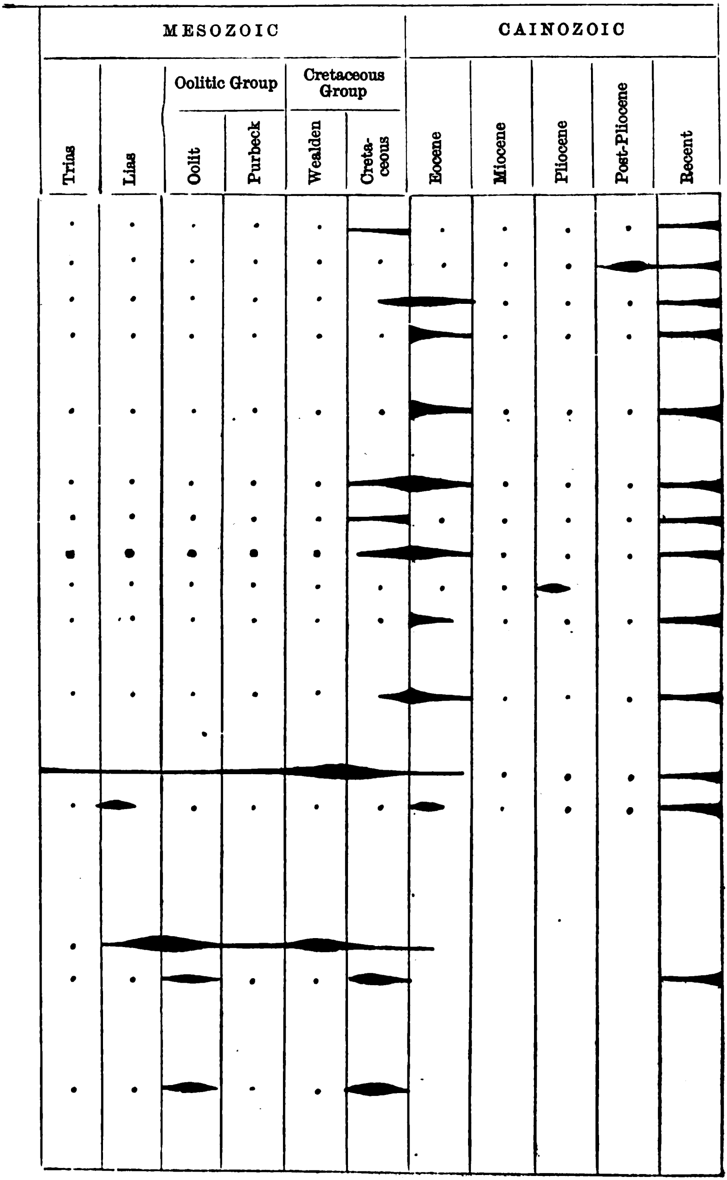
Oolitic Group
Cretaceous Group
Trias
Lias
Oolite
Purbeck
Wealden
Cretaceous
Eocene
Miocene
Pliocene
Post-Pliocene
Recent

Classes, Orders, and Families	Palæozoic: Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
Fam. Scopellidæ . . .	.		.	.	.	.
— Esocidæ . . .	.	.	.	.	.	.
— Clupeidæ	.	.	.	.	.	.
— Murænidæ . . .	.	.	.	.	.	.
Sub-Order B. *Anacanthini.*	.	.				
Fam. Gadidæ	.	.	.	.	.	.
Sub-Order C. *Acanthopteri.*	.	.				
Fam. Percidæ . . .	.	.	.	.	.	.
— Mugilidæ	.	.	.	.	.	.
— Scomberidæ . . .	.	.	.	.	.	.
— Squammipennes . . .	.	.	.	.	.	.
— Lophiidæ . . .	.	.	.	.	.	.
Sub-Order D. *Pharyngognathi.*						
Fam. Scomberesocidæ . . .	.	.	.	.	.	.
Order Ganoidei.						
Sub-Order *Lepidosteidæ* (*Saurodei*)	.	.	.	▬	▬	▬
Fam. Chondrosteidæ . .	.	.	.	.	.	.
— Cephalaspidæ . . .	.	.	▬	▬		
— Placodermi . . .	.	.	.	▬		
— Acanthodidæ . . .	.	.	.	▬	▬	
— Pycnodontidæ . .	.	.	.	.	▬	▬
— Crossopterigidæ . . .	.	.	.	▬	▬	▬
— Saurodipterini . . .	.	.	.	▬	▬	
— Glyptodipterini . . .	.	.	.	▬	▬	
— Cœlacanthini . . .	.	.	.	.	▬	▬
— Phaneropleurini . . .	.	.	.	▬		
— Ctenodipterini . .	.	.	.	▬		


MESOZOIC
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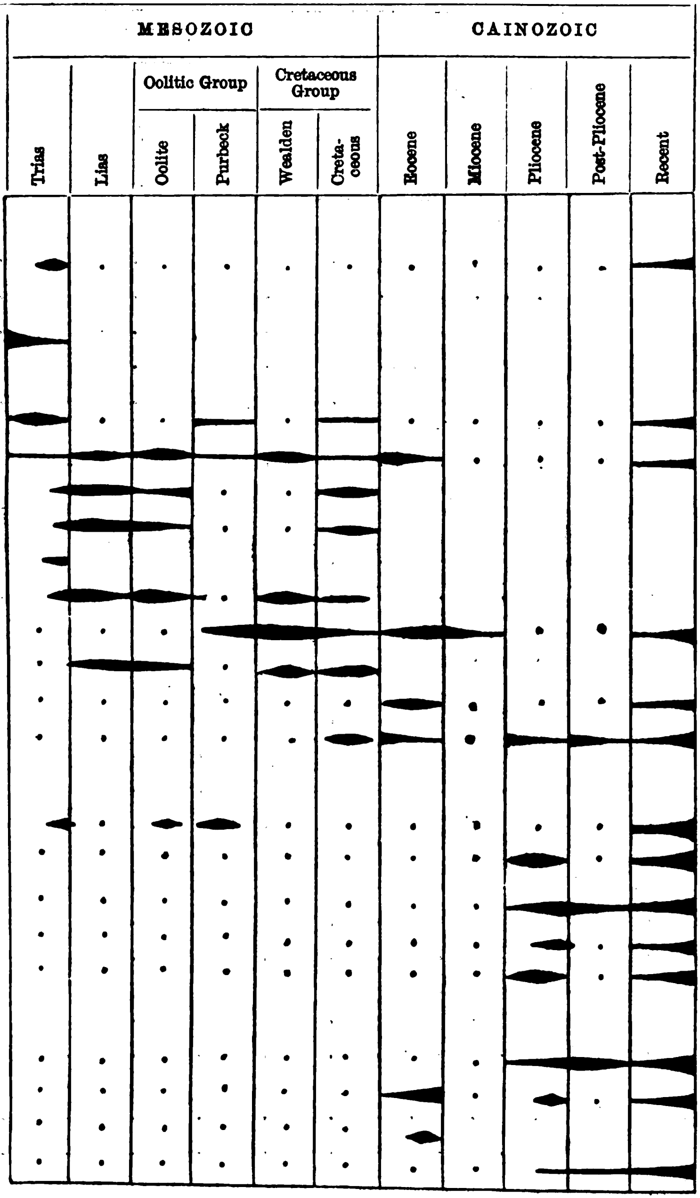
Recent

Classes, Orders, and Families	Palæozoic					
	Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
Order Dipnoi.						
Fam. Sirenidæ (*Ceratodus*)	.	.	.	.	.	.
Class Amphibia.						
Order Labyrinthodontia	.	.	.	.		
Class Reptilia.						
Order Lacertilia	.	.	.	.	.	
— Crocodilia	.	.	.	.	.	.
— Ichythopterygia	.	.	.	.	.	.
— Sauropterygia	.	.	.	.	.	.
— Anomodontia	.	.	.	.	.	.
— Deinosauria	.	.	.	.	.	.
— Chelonia	.	.	.	.	.	.
— Pterosauria	.	.	.	.	.	.
— Ophidia	.	.	.	.	.	.
Class Aves	.	.	.	.	.	.
Class Mammalia.						
Order Marsupialia	.	.	.	.	.	.
— Sirenia	.	.	.	.	.	.
— Cetacea						
Fam. Balænidæ	.	.	.	.	.	.
— Rhynchocæti	.	.	.	.	.	.
— Delphinidæ	.	.	.	.	.	.
Order Ungulata.						
Sec. A. *Perissodactyla.*						
Fam. Rhinoceridæ	.	.	.	.	.	.
— Tapiridæ	.	.	.	.	.	.
— Palæotheridæ	.	.	.	.	.	.
— Equidæ		.	.	.	.	.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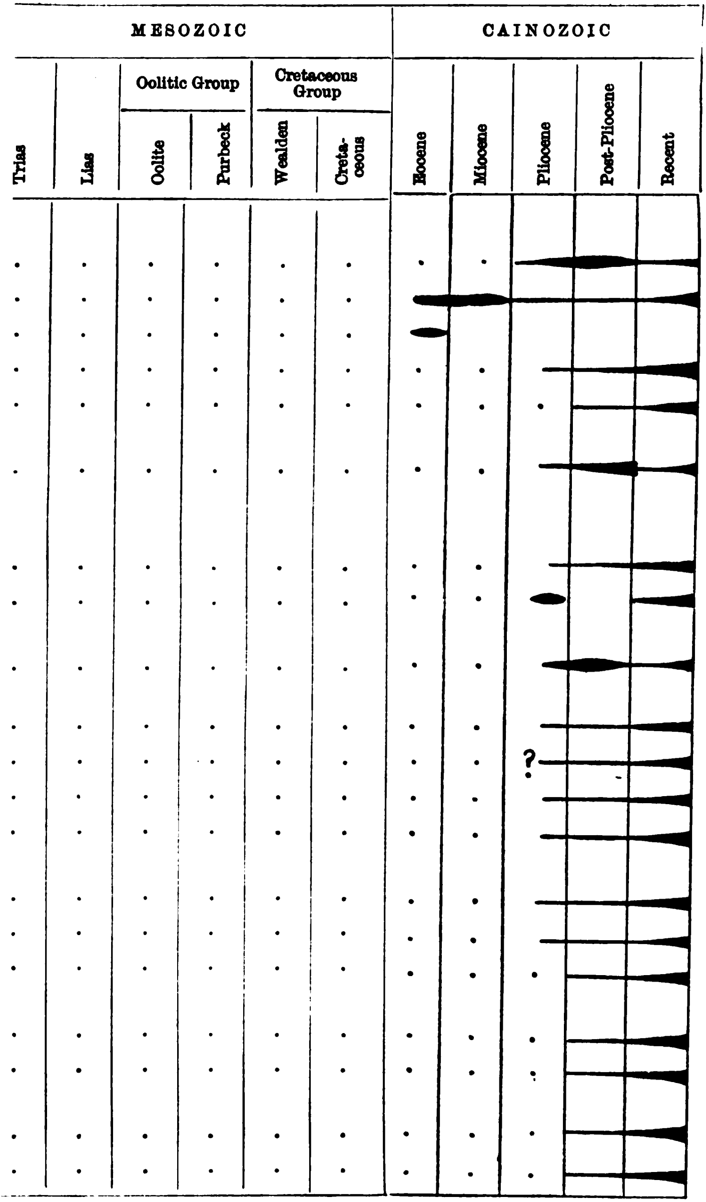
Classes, Orders, and Families	Palæozoic				
	Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous
Sec. B. *Artiodactyla.*					
Fam. Hippopotamidæ . .	.	.	.	.	.
— Suidæ	.	.	.	.	.
— Anoplotheridæ . .	.	.	.	.	.
— Cervidæ	.	.	.	.	.
— Bovidæ . . .	.	.	.	.	.
Order Proboscidea.					
Fam. Elephantidæ . . .	.	.	.	.	.
Order Carnivora.					
Sec. 1. *Pinnigrada.*					
Fam. Phocidæ . . .	.	.	.	.	.
— Trichicidæ . . .	.	.	.	.	.
Sec. 2. *Plantigrada.*					
Fam. Ursidæ	.	.	.	.	.
Sec. 3. *Digitigrada.*					
Fam. Mustellidæ . . .	.	.	.	.	.
— Hyænidæ	.	.	.	.	.
— Canidæ . . .	.	.	.	.	.
— Felidæ	.	.	.	.	.
Order Rodentia.					
Fam. Leporidæ . . .	.	.	.	.	.
— Castoridæ	.	.	.	.	.
— Muridæ . . .	.	.	.	.	.
Order Cheiroptera.					
Fam. Vespertilionidæ . . .	.	.	.	.	.
— Rhinolophidæ . . .	.	.	.	.	.
Order Insectivora.					
Fam. Talpidæ	.	.	.	.	.
— Soricidæ . . .	.	.	.	.	.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INDEX.

The Fossils, the names of which are printed in Italics, are figured in the Text.

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SPOTTISWOODE AND CO., NEW-STREET SQUARE
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